Fourier Analysis Method for Asymmetric Polarization-Maintaining Fiber Alignment

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Abstract: A new method for alignment of asymmetric polarization-maintaining (PM) fibers has been developed. It improves alignment accuracy for PM fibers with asymmetric stress applying parts. It provides a fast and accurate universal method for splicing recently developed PM fiber types.

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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, such as PAS method [3], end-view method [4], POL method [5,6], and IPA method [7]. However, each existing method has its limitations and drawbacks. Furthermore, there has been a proliferation of specialized PM fibers in recent years for sensor and fibers laser applications that are difficult to align by any previous method [8]. End-view images of some typical PM fibers in the market are shown in figure 1.

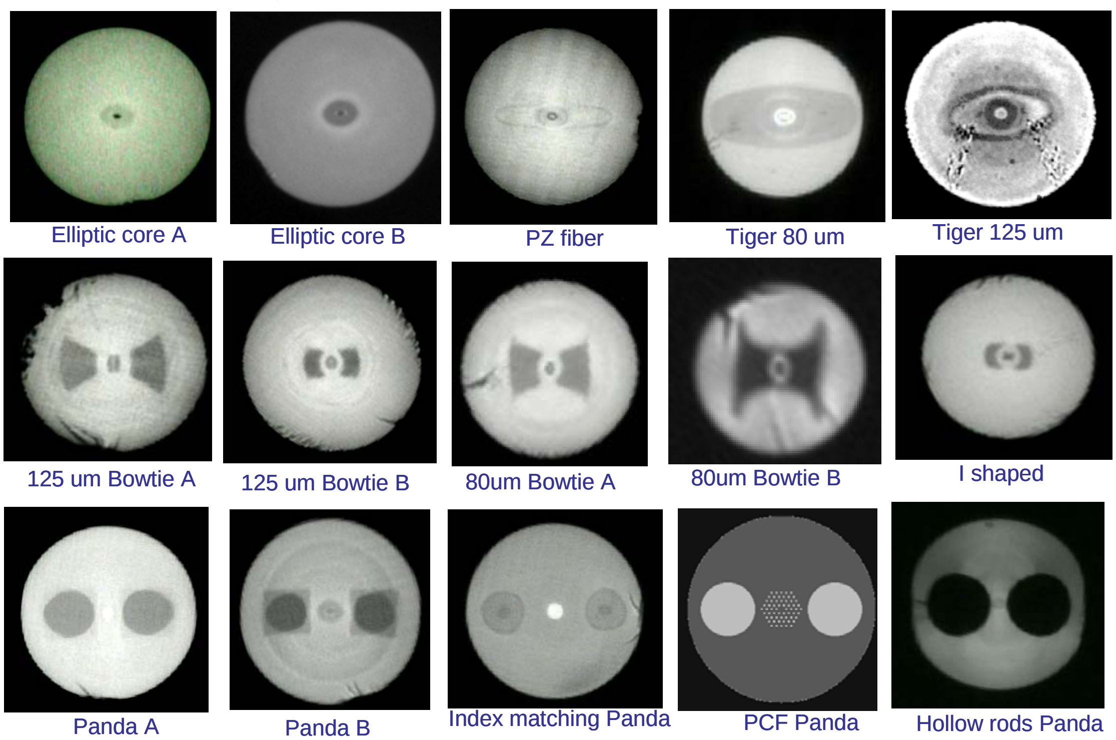


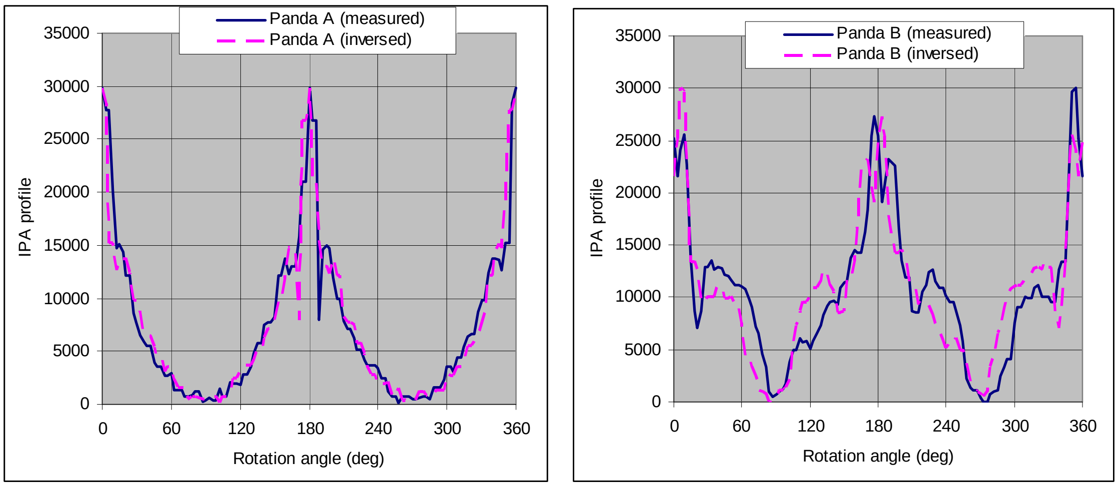
Fig. 1. Some examples of typical PM fiber types

A detailed comparison and discussion on the different PM fiber alignment methods can be found in [7]. Among those methods, the IPA method demonstrates best flexibility for geometry variation of existing PM fibers and quick adaptability to new PM fiber designs. Many PM fiber types which were difficult to align with other methods can be aligned with the IPA method. However, since the current IPA method utilizes linear correlation of IPA profiles [7] for the alignment, it may yield a few degrees of angle alignment error if a fiber is geometrically asymmetric after the manufacturing process. The geometric asymmetry of stress applying parts is a well known issue and does not have a major impact on PM fiber performance. The degree of asymmetry may vary by fiber lots for the same fiber design.

It is very difficult to automate angle compensation with the IPA correlation method. In this article, a new method is described which provides the adaptability of IPA method but reduces the sensitivity to fiber asymmetry.

2. IPA with Fourier analysis

IPA profiles measured using two types of Panda fibers are plotted in Fig.2. Panda A is from a vendor with more than 20 years Panda production experience. Panda B is from a newly established Panda manufacturer. Reversed IPA profiles (dashed pink lines) are also plotted in the same chart to show the symmetry of each profile. With IPA correlation method, Panda A can be aligned to 0.5 degree average angle offset, while Panda B can only reach 2 degrees to 5 degrees depending on the random fiber orientation. To improve the alignment accuracy for highly asymmetric fibers like Panda B, we need to search for a new method which is less dependent on fiber symmetry.



(a) IPA profile of a symmetric Panda fiber

(b) IPA profile of an asymmetric Panda fiber

Fig. 2. Typical IPA profiles of Panda fibers. The solid blue curves are measured IPA and the dashed pink curves are inversed for symmetry observation. The asymmetric Panda fiber (b) can easily cause a few degrees of angle error in PM alignment

Instead of using the linear correlation method, Fourier analysis method can also be used to analyze the IPA profiles. Since all IPA profiles are periodic functions with a period of 360 degree, they can be expanded in to Fourier series. The expansion coefficients carry all characteristics of the IPA profiles.

$$f(x) \approx \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos n\omega x + b_n \sin n\omega x); \quad \omega = \frac{2\pi}{T}$$

$$where, \quad a_n = \frac{T}{2}\int_0^T f(x)\cos n\omega x\, dx; \; n = 0, 1, 2,...$$

$$b_n = \frac{T}{2}\int_0^T f(x)\sin n\omega x\, dx; \; n = 1, 2,...$$

In above formula, $f(x)$ is an IPA profile and $T = 2\pi$ (360 deg). For all the PM fibers symmetric to $T/4$ (90 deg), Fourier coefficients b_n will be 0, where n = 1, 2, 3, …. Similarly, for all the PM fibers symmetric to $T/2$ (180 deg), the odd coefficients a_n and b_n will be 0, where n = 1, 3, 5, … Since most IPA profiles should be symmetric to both 90 and 180 deg, theoretically non zero coefficients should be only even terms of a_n, where n = 0, 2, 4,…

By defining of

$$R = \frac{(A_{odd} + B_{odd} + B_{even})}{A_{even}}$$

$$where, \quad A_{odd} = \sqrt{\sum_{n=0}^{\infty} a_{2n+1}{}^2}; \quad A_{even} = \sqrt{\sum_{n=1}^{\infty} a_{2n}{}^2}; \quad A_{sum} = \sum_{n=0}^{\infty} a_n;$$

$$B_{odd} = \sqrt{\sum_{n=0}^{\infty} b_{2n+1}{}^2}; \quad B_{even} = \sqrt{\sum_{n=1}^{\infty} b_{2n}{}^2}$$

and rotating the IPA profile $f(x+\delta)$ with a rotation angle of δ degree digitally (not physically), we can search the minimum of R. The δ which makes R minimum and A_{sum} positive should be the correct alignment angle of a PM fiber. For asymmetric PM fibers, their Fourier coefficients b_n are actually not zero. We can therefore use those non-zero b_n to automatically compensate the alignment angles.

3. Test summary

The Fourier Analysis Method has been tested with more than 250 IPA profiles from splices of 12 different PM fiber types (shown in Table 1). For fiber types with good symmetry, such as 125 um Panda A, 125 um Bowtie A, etc., the average angle offset error can be as low as 0.35 deg. For the fiber types with relatively large asymmetry, such as 80 um Bowtie and 125 um Panda B, the alignment error is reduced when comparing to the correlation methods. Considering that typical requirement of alignment accuracy is 25 dB crosstalk (3.22 deg angle error) for many applications, the Fourier analysis method can provide substantial quality improvement for PM fiber splicing.

Table 1. Average alignment error (difference between the measured and computed angle offset) with 3 different methods: Direct correlation, indirect correlation, and Fourier analysis for more than 250 IPA profiles from splices of 12 fiber combinations

Fiber Combinations	Splice samples	Average angle error (deg)			STD of angle error (deg)		
		Direct correlation	Indirect correlation	Fourier analysis	Direct correlation	Indirect correlation	Fourier analysis
80um Panda A + 80um Panda A	8	1.73	1.14	0.91	1.20	1.13	0.85
80um Bowtie A + 80um Bowtie A	17	3.44	4.50	1.37	2.61	3.99	1.44
80um Panda A + 80um Panda B	12	1.36	4.26	1.30	1.40	1.96	0.60
80um Panda B + 80um Elliptic Core B	12	1.22	1.79	1.83	1.12	1.27	1.32
125um Panda A + 125um Panda A 980nm	19	1.30	1.07	0.91	0.83	0.98	0.75
125um Panda A + 125um Panda A 1550nm	5	0.76	0.48	0.35	0.16	0.20	0.29
125um Bowtie A + 125um Bowtie A	15	0.94	0.50	0.39	0.71	0.35	0.41
Panda B Yb + Double Clad Panda	49	1.03	0.85	1.03	0.81	0.67	0.74
125um Panda A + 125um Panda B	80	2.81	2.31	1.34	1.92	1.41	0.99
125um Bowtie A + 125um Panda A	20	N/A	0.90	0.93	N/A	0.63	0.56
Index matching Panda + Panda YDF	12	0.88	0.78	0.42	0.58	0.59	0.23
125 um Panda C + 125 um Panda C	14	1.15	0.58	0.31	1.07	0.65	0.31
Total / Average	**263**	**1.84**	**1.71**	**1.06**	**1.72**	**1.85**	**0.92**

3. References

[1] Yamauchi, R, "Specialty fibers", Lasers and Electro-Optics Society Annual Meeting, 1994. LEOS '94 Conference Proceedings. IEEE, Vol 2, pp.228 – 229, 31 Oct.-3 Nov. 1994.
[2] Segi, T.; Ouchi, Y.; Nishiwaki, K.; Sakai, T.; Nishide, K.; Wada, A, "Polarization-maintaining EDFA for optical sensing application, composed of PANDA fiber based low loss and low cross-talk optical components," Optical Fiber Sensors Conference Technical Digest, pp. 289 - 292 vol.1 6-10 May 2002.
[3] Itoh, K; Yoshinuma, N; Suzuji, N; Yamada, T; Taya, H, "Method of fusion-splicing polarization maintaining optical fibers," United States Patent 5013345, May 7. 1991.
[4] Itoh, K; Yamada, T; Onodera, T; Yoshinuma, M; Kato, Y. "Apparatus for fusion-splicing a pair of polarization maintaining optical fibers," United States Patent 5147434, Sept. 15, 1992.
[5] W. Zheng, "Automated Fusion-Splicing of Polarization Maintaining Fibers," J. Lightwave Technol. 15, 125-134, 1997.
[6] W. Zheng, "Automated alignment and splicing of different PM-fiber types." Fiber Optic Gyros: 20th Anniversary Conference**,** Denver, 1996
[7] W. Zheng, D. Duke, T. Kubo, and B. Malinsky, "Interrelation Profile Analysis Method for Alignment of Polarization-Maintaining Fiber," OFC/NFOEC2010, March. 25, 2010.
[8] Carter, A.; Samson, B., "PANDA-style fibers move beyond telecom", Nufern Article, http://www.nufern.com/article_detail.php/20, Aug. 2, 2004.