EFFECTS OF EXTERNAL TWISTS ON POLARIZATION MODE DISPERSION OF SINUSOIDALLY SPUN FIBERS

Sait Eser Karlik[1] Gunes Yilmaz[2] Ender Yilmaz[3]

[1,2] Uludag University, Faculty of Engineering and Architecture, Department of Electronics Engineering, 16059, Gorukle, Bursa, Turkey
[3]Bogazici University, Faculty of Engineering, Department of Electrical and Electronics Engineering, 34342, Bebek, Istanbul, Turkey
[1]e-mail:ekarlik@uludag.edu.tr [2]e-mail:gunesy@uludag.edu.tr [3]e-mail:ender.yilmaz@gmail.com

Keywords: Optical fiber communication, PMD, sinusoidally spun fibers, external twists

Abstract- Low polarization mode dispersion (PMD) fibers are very essential for reliability of long haul high bit rate transmission systems. An efficient method for reducing PMD of optical fibers is fiber spinning. Sinusoidal spinning is a widely used method in fiber spinning. In this paper, we report experimental analysis of effects of external twists on PMD of unspun and sinusoidally spun fibers. Results show that for similar external twist rates, there is a similarity between PMD values of unspun and sinusoidally spun fibers used in experiments. Therefore, we propose that analytical formula previously proposed for unspun fibers can be also used for sinusoidally spun fibers with some exceptions.

I. INTRODUCTION

Dispersion is the main factor limiting the transmission capacity of optical fiber. Pulse broadening due to dispersion causes inter-symbol interference (ISI) to occur and increases bit error rate (BER) of the communication system. Polarization mode dispersion (PMD) is a type of dispersion that has been known since 1970s. In current high bit rate long haul transmission systems, PMD is the main factor causing degradation in system performance. Therefore, it must be reduced to achieve a reliable high bit rate communication. For installed high-PMD fibers, several PMD compensation methods have been proposed [1-4]. For fibers currently manufactured, an efficient method used in reducing fiber PMD is the fiber spinning method that provides controlled polarization mode coupling [5]. PMD performance of spun fibers has been investigated by using various modelling methods and in particular with simulations [6, 7]. An important factor effecting polarization mode coupling in optical fibers is external twists applied to the fiber. Effects of external twists on PMD of unspun fibers were theoretically and experimentally analysed in [8] and [9]. It was reported in [10] and [11] that twist can be an important external factor causing PMD fluctuations in spun fibers.

In this paper, experimental analysis of PMD performances of sinusoidally spun fibers under different external twist rates is reported. Experiments were performed on both unspun and sinusoidally spun fibers and differential group delay (DGD) measurements were made to determine effects of external twists on PMD of sinusoidally spun fibers.

In the second section, fiber spinning and spin types are described. In the third section, the measurement method is given. In the fourth section, experimental results of unspun fibers are interpreted. In the fifth section, experimental results of sinusoidally spun fibers are compared.

II. FIBER SPINNING AND SPIN TYPES

The process of fiber spinning was first reported by Barlow et al. in 1981 [12]. The proposed method for production of the spun fiber was to rotate the preform around its axis during the draw. However, fiber spinning was not widely used in fiber production until the middle of 1990s due to two main factors. One factor was the relatively low bit rates of optical networks in that time (≤2.5 Gb/s). Therefore, PMD was not a major problem in those networks. The other factor was the difficulty in rotating the preform at high speeds. A more practical method proposed by Hart et al. [13] was the direct spinning of the fiber instead of the preform. With this method, spinning process began to be widely used in fiber production.

Currently, various types of spun fibers are manufactured. The most common ones are constantly and sinusoidally spun fibers. Also, the frequency-modulated (FM) and amplitude-modulated (AM) spun fibers, which were proposed recently [14], become widespread. The spin profiles of these types are shown in Fig. 1.

The spin profile of constantly spun fiber has a constant value of α_0.

$$\alpha(z) = \alpha_0 \quad (1)$$

The constant spinning is simple and easy to model. The PMD reduction efficiency depends on fiber beat length. Therefore, this type of spinning is not effective for short beat lengths with a low spin rate. The most important drawback of constant spinning is that it causes elastic twist in spooled fibers.

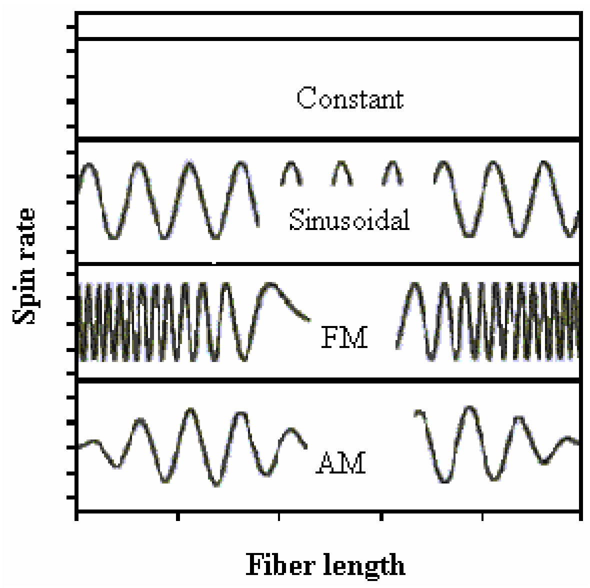

Fig. 1. Different types of spin profiles

In sinusoidal spinning, fiber rotates around its axis alternatively clockwise and counter-clockwise to prevent the introduction of elastic twist on the fiber wound on the bobbin. Therefore, sinusoidal spinning can reduce the fiber PMD to a lower value than that of constant spinning.

The sinusoidal spin profile is in the form of

$$\alpha(z) = \alpha_0 \sin(\eta z) \quad (2)$$

where α_0 is the spin magnitude in radians, $\eta=2\pi/\Lambda$, Λ is the spin period in meters and z is the fiber length. Taking the derivative of (2) with respect to the fiber length, the resultant $\alpha'=d\alpha/dz$ is called the rotation frequency of the fiber axis and it can be written as

$$\alpha'(z) = 2\pi \frac{\alpha_0}{\Lambda} \cos(\frac{2\pi}{\Lambda} z) \quad (3)$$

The rms value of (3) is called the effective spinning rate and it can be computed with

$$\gamma_{rms} = \frac{2\pi}{\sqrt{2}} \frac{\alpha_0}{\Lambda} \quad (4)$$

Although PMD can be reduced to very low values in sinusoidally spun fibers, variations in fiber beat length can negatively affect the PMD performance of the cable.

To solve this problem, FM and AM spin profiles are proposed [14]. As shown schematically in Fig. 1, these profiles take the form

$$\alpha(z) = \alpha_0 \sin\left\{2\pi\left[f_0 z + f_m \sin(\frac{2\pi z}{\Lambda})\right]\right\} \quad (5)$$

in FM spun fibers and

$$\alpha(z) = \alpha_0 \sin(2\pi f z) \sin(\frac{2\pi z}{\Lambda}) \quad (6)$$

in AM spun fibers. Good PMD reduction can be achieved over a wide range of fiber beat lengths in FM and AM spun fibers.

III. THE MEASUREMENT METHOD

In measurements, external twists were applied to four fibers that were all 150 m in length and DGD measurements were performed in the wavelength range of 1520-1630 nm. Two of fibers used were unspun fibers (USF1 and USF2) while the other two (SSF1 and SSF2) were spun fibers produced by sinusoidal spinning of unspun fibers USF1 and USF2. The spin magnitude was 4π and the spin period was 2m for both fibers. Therefore, the effective spinning rates of both fibers were 4.4 turns/m (or 27.6 rad/m).

In all measurements, Jones matrix method based PAT9000F PMD/PDL analyzer and Agilent 81640A tunable laser source were used.

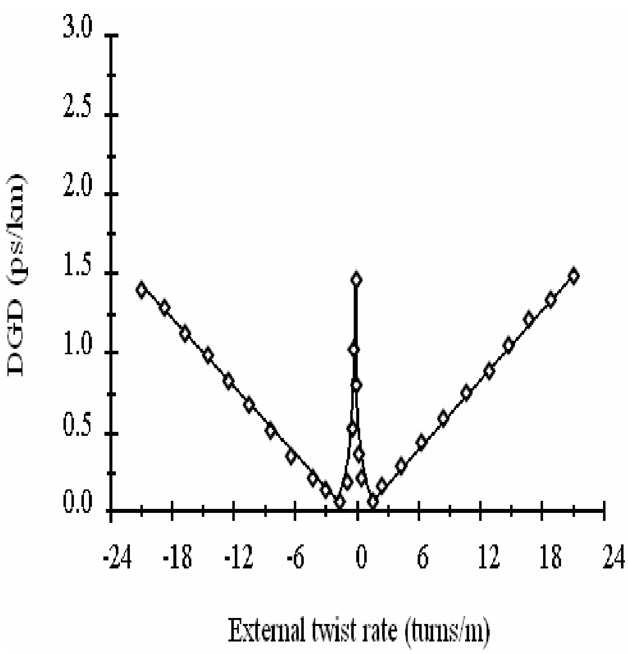

Fig. 2. DGD values measured for USF1 under different external twist rates

IV. EXPERIMENTAL RESULTS OF UNSPUN FIBERS

Measured DGD values of USF1 and USF2 under zero external twist rate are shown in Figs. 2 and 3. As shown in Figs. 2 and 3, measured DGD values of USF1 and USF2 under zero external twist rate are 1.47 ps/km and 2.53 ps/km, respectively.

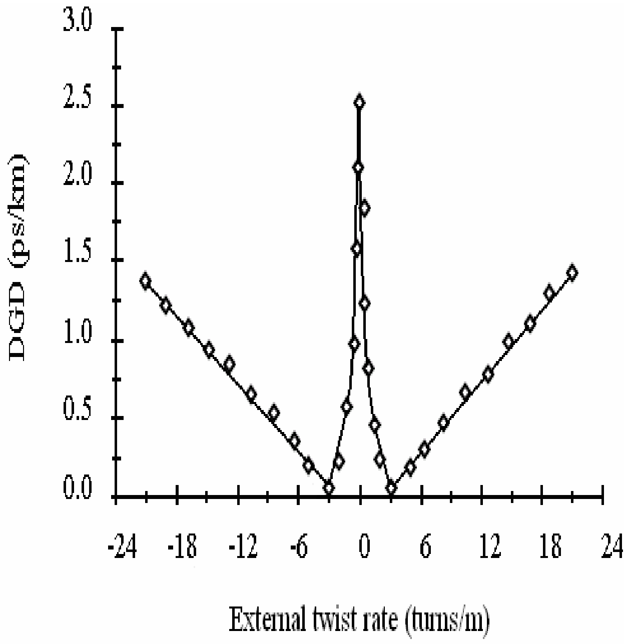

Fig. 3. DGD values measured for USF2 under different external twist rates

When external twist is applied on an unspun fiber, DGD of fiber can be computed with [8]

$$DGD = \frac{\delta\beta_L \delta\beta_L^{'} + (\delta\beta_C - 2\gamma)\delta\beta_C^{'}}{\sqrt{\delta\beta_L^2 + (\delta\beta_C - 2\gamma)^2}} \qquad (7)$$

where $\delta\beta_L$ is the linear birefringence, γ is the applied external twist and $\delta\beta_C$ is the circular birefringence induced by external twists. $\delta\beta_L^{'}$, $\delta\beta_C$ and $\delta\beta_C^{'}$ can be computed with $\delta\beta_L^{'} = \frac{d(\delta\beta_L)}{d\omega} \approx \frac{\delta\beta_L}{\omega}$, $\delta\beta_C = g\gamma$, $\delta\beta_C^{'} = \gamma\frac{dg}{d\omega}$, respectively, where g is the rotation coefficient and ω is the angular frequency. For $\gamma = 0$, $\delta\beta_C = 0$ and $\delta\beta_C^{'} = 0$. Then, (7) can be written as

$$DGD = \delta\beta_L^{'} \approx \frac{\delta\beta_L}{\omega} \qquad (8)$$

Since ω is the same for both fibers used in measurements, the DGD ratio of fibers will be approximately equal to the ratio of linear birefringence values when no external twist exists.

For USF1, $\delta\beta_L$=1.7 rad/m, $\omega/\delta\beta_L\ d(\delta\beta_L)/d\omega$=1, g = 0.14, $\omega/g\ dg/d\omega$= 0.09 and for USF2, $\delta\beta_L$=3 rad/m, $\omega/\delta\beta_L\ d(\delta\beta_L)/d\omega$=1, g = 0.14, $\omega/g\ dg/d\omega$= 0.088.

Since the linear birefringence of USF2 is about twice of that of USF1, a similar ratio occurs between DGD values of fibers.

Examining other DGD values in Figs. 2 and 3, it is obvious that DGD increases almost linearly with external twist. This result is in good agreement with the analytical solution given in (7). Another important point is that DGD approaches to zero when external twist rates of ± 1.75 turns/m and ± 3 turns/m are applied to USF1 and USF2, respectively. This also fits to (7).

V. EXPERIMENTAL RESULTS OF SINUSOIDALLY SPUN FIBERS

DGD values of SSF1 and SSF2 measured under different external twist rates are shown in Figs. 4 and 5, respectively.

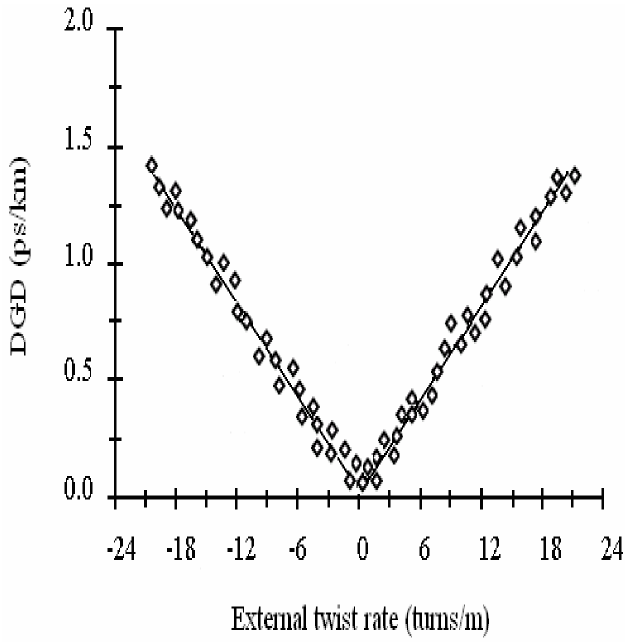

Fig. 4. DGD values measured for SSF1 under different external twist rates

In Fig. 4, DGD of SSF1 reaches to zero when no external twist exists. At other points, DGD increases almost linearly with external twist rate just like the case in USF1 and takes similar values to that of USF1. We think that the reason is due to the same initial linear birefringence values of SSF1 and USF1 since SSF1 was produced by sinusoidal spinning of USF1.

Contrary to DGD values of SSF1 in Fig. 4, DGD values of SSF2 in Fig. 5 exhibit significant fluctuations around zero external twist, i.e. in the range of -6 turns/m - +6 turns/m, instead of reducing down to zero.

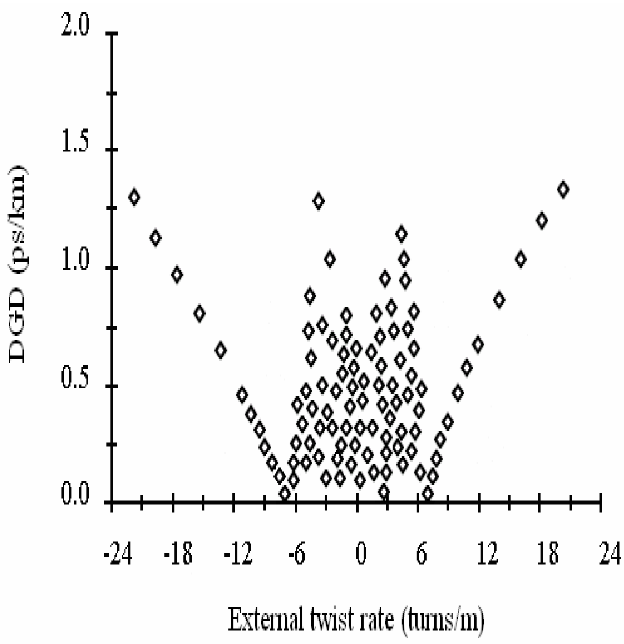

Fig. 5. DGD values measured for SSF2 under different external twist rates

These fluctuations, which can rise to the half of the DGD value of USF2 at zero external twist rate, are undesirable and greater rms spin rates may be selected for SSF2 to overcome this problem. At external twist rates excluding the range stated above, SSF2 behaves like USF2.

VI. CONCLUSION

In this paper, experimental analysis of effects of external twist on PMD of unspun and sinusoidally spun fibers is reported.

Excluding approximate ranges of -3 turns/m - +3 turns/m for USF1 and SSF1 and -6 turns/m - +6 turns/m for USF2 and SSF2, there is a similarity between PMD values of unspun and sinusoidally spun fibers for similar external twist rates used in measurements. The reason is probably due to the same initial linear birefringence values of sinusoidally spun and unspun fibers. Therefore, we propose that analytical formula previously proposed for unspun fibers can be also used for sinusoidally spun fibers in a wide twist rate range. The exceptional range around zero twist rate can be narrowed by choosing proper rms spin rates which is the subject of further research.

REFERENCES

[1] T. Merker, A. Schwarzbeck and P. Meissner, 'PMD compensation up to second order by tracking the principle states of polarization using a two-section compensator', Optics Commun., 198 (1-3), pp. 41-47, 2001.

[2] X. Zhang, Y. Xia, Y. Huang and X. Ren, 'A novel tunable PMD compensation using linearly chirped fiber Bragg grating', Optics Commun., 214 (1-6), pp. 123-127, 2002.

[3] K. Ikeda, 'PMD compensator with second-order PMD mitigation using mode-coupled fixed delay', IEEE Photonics Technology Letters, 16 (1), pp. 105-107, 2004.

[4] F. Buchali and H. Bulow, 'Adaptive PMD compensation by electrical and optical techniques', J. Lightwave Tech., 22 (4), pp. 1116-1126, 2004.

[5] D. A. Nolan, X. Chen and M. –J. Li, 'Fibers with low polarization-mode dispersion', J. Lightwave Tech., 22 (4), pp. 1066-1077, 2004.

[6] A. Pizzinat, L. Palmieri, B.S. Marks, C.R. Menyuk and A. Galtarossa, 'Analytical treatment of randomly birefringent periodically spun fibers', J. Lightwave Tech., 21 (12), pp. 3355-3363, 2003.

[7] A. Galtarossa, P. Griggio, L. Palmieri and A. Pizzinat, 'First- and second-order PMD statistical properties of constantly spun randomly birefringent fibers', J. Lightwave Tech., 22 (4), pp. 1127-1136, 2004.

[8] R.E. Schuh, E.S.R. Sikora, N.G. Walker, A.S. Siddiqui, L.M. Gleeson and D.H.O. Bebbington, 'Theoretical analysis and measurement of effects of fibre twist on polarization mode dispersion of optical fibres', Electronics Lett., 31 (20), pp.1772-1773, 1995.

[9] A. Galtarossa and L. Palmieri, 'Measure of twist-induced circular birefringence in long single-mode fibers: theory and experiments', J. Lightwave Tech., 20 (7), pp. 1149-1159, 2002.

[10] M.J. Li, A.F. Evans, D.W. Allen and D.A. Nolan, 'Effects of lateral load and external twist on PMD of spun and unspun fibers', Proc. ECOC'99, Vol. 2, pp. 62-63, 1999.

[11] S.E. Karlik and G. Yilmaz, 'Investigation of effects of external twists on polarization mod dispersion of constantly spun fibers', Proc. ELECO'04, Vol. 2, pp. 198-201, 2004 (in Turkish).

[12] A.J. Barlow, J.J.R. Hansen and D.N. Payne, 'Birefringence and polarization mode-dispersion in spun single-mode fibers', Appl. Opt., vol. 20, p. 2963, 1981.

[13] A. C. Hart, R. G. Huff and K. L. Walker, 'Method of making a fiber having low polarization mode dispersion due to a permanent spin', U.S. Patent 5 298 047, 1994.

[14] M. J. Li and D. A. Nolan, 'Fiber spin-profile designs for producing fibers with low polarization mode dispersion', Opt. Lett., vol. 23, pp. 1659-1661, 1998.