Measurement of precursor linear birefringence beat length of spun fibre using polarization reflectometry

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Abstract

It is well known that the performance of a Fibre Optic Current Sensor (FOCS) based on a spun fibre is essentially determined by the ratio of the fibre's precursor linear birefringence beat length (L_B) to the spun period (S_P). Specifically, the knowledge of L_B plays a vital role in determining the temperature influence and the accurate modelling of the FOCS. However, in practice, the value of L_B provided by the manufacturers is a rough estimate rather than an accurate one. So, a measurement technique based on a polarization reflectometer, such as POTDR or POFDR, is proposed for L_B measurement of a spun fibre with cm range S_P; furthermore, the proposed technique also provides information on the S_P of the spun fibre. The measurement technique under discussion is demonstrated theoretically and experimentally. The measured L_B of the spun fibre is in good agreement with the L_B of the unspun fibre drawn from the same preform, and the measured S_P agrees with the value provided by the manufacturer.

Introduction

Ever since its proposal, the Polarization Optical Time Domain Reflectometer (POTDR) has remained an interesting technique to investigate the polarization properties of optical fibres [1]. The underlying principle of the technique is that in single-mode fibres the Rayleigh backscattered light contains information on the spatial distribution of the State of Polarization (SOP) along the fibre. Besides its widespread use in many sensing applications, the POTDR technique is also used to measure the beat length of single-mode fibres owing to its simple and non-destructive measurement ability [2].

Single-mode fibre preform rotated during the fibre drawing process results in a spun fibre. These fibres exhibit a reduced global linear birefringence owing to spinning, while the local linear birefringence remains intact. Thus, due to the spinning process, in general, it is not straightforward to measure the precursor beat length (L_B) of the spun fibre, unlike single-mode fibres. In this paper we present a method for L_B measurement in spun fibres, with cm range S_P, using a Polarization Optical Frequency Domain Reflectometer (POFDR). In addition to L_B measurement, the proposed technique also provides information on S_P. It must be noted that POFDR is the frequency domain equivalent of the POTDR. The choice of POFDR over POTDR is owing to its high spatial resolution and low noise level. In what follows next, the POFDR based L_B measurement of the spun fibre is shown theoretically and experimentally.

Measurement technique: Theory

The proposed here polarization reflectometry-based L_B measurement of a spun fibre is based on twisting the spun fibre at a rate τ that cancels the birefringence axes rotation due to spinning [3]:

$$\tau = \frac{-\xi}{\left(1 - \frac{g}{2}\right)} \quad (1)$$

where $\xi = \frac{2\pi}{S_P}$ is the spun rate, $g = 0.146$ is the photo-elastic coefficient of silica. Note that the $-$ sign before the ξ indicates that twist is against the spin orientation. When a spun fibre is twisted at a rate according to Eq. (1), the birefringence axes rotation of the spun fibre is cancelled, and the precursor linear birefringence $\left(\Delta\beta = \frac{2\pi}{L_B}\right)$ of the spun fibre reappears along with photo-elastic circular birefringence rotation, $\alpha = \frac{g}{2}\tau$. In other words, a spun fibre of length z twisted according to Eq. (1) will be equivalent to a pure linear retardation $R(z)$ followed by a pure rotation $\Omega(z)$ [3]:

$$R(z) = \Delta\beta z \quad (2)$$

$$\Omega(z) = \alpha z \quad (3)$$

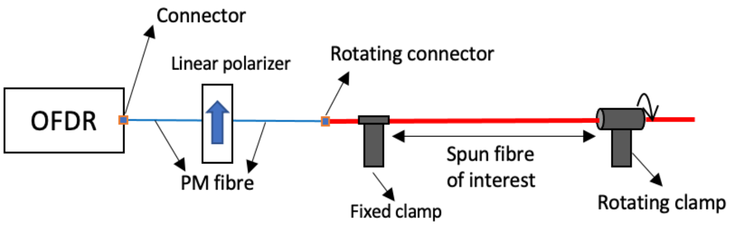

Fig.1. POFDR setup for L_B measurement of spun fibre

Under POFDR investigation such a fibre behaves only as a linearly birefringent fibre with pure retardation $R(z)$ because the (reciprocal) rotation $\Omega(z)$ is cancelled after the roundtrip propagation [4]. Thus, by launching a linear SOP into such a fibre the backscattered power at the POFDR receiver oscillates with a period $\frac{L_B}{2}$, facilitating a way to measure the L_B of the spun fibre. The schematic of the POFDR based experimental setup for the L_B measurement of a spun fibre is shown in Fig.1. As shown in the figure the spun fibre of interest is placed in between the fixed and rotating clamps and is twisted using the rotating clamps. The rotating connector connecting the polarizer and the spun fibre is used to adjust the azimuth of the light launched into the spun fibre.

The measurement technique can be further elucidated by simulating the experimental setup under different conditions. Fig. 2 illustrate the simulated normalized backscattered POFDR trace of a 0.85 m long spun fibre with L_B of 0.5 m and S_P of 8 cm for different SOP azimuth angles and different level of spinning compensation. Fig. 2(a) shows the backscattered trace when the spinning effect is completely compensated. So, the period of oscillation is $\frac{L_B}{2} = 0.25$ m as expected, however, the amplitude of the oscillation is maximum when a 45° linear SOP w.r.t the polarization modes is launched, and it decreases as the azimuth deviates from 45° SOP. This is because at 45° maximum power transfer between the modes occur. Fig. 2(b) &(c) shows the effect of different levels of spinning compensation (from 80-100%) for 5° and 35° linear SOP, respectively. When a 5° linear SOP is launched L_B value is measurable only at 100% spin compensation, whereas for 35° linear SOP even at 99% spin compensation an approximate value of L_B can be deduced, indicating the closer the azimuth of the linear SOP to 45° the better the L_B measurement. Fig. 2(d) shows the effect of spinning compensation between 99-100%

for 35° linear SOP. When the compensation is not 100% the amplitude of the oscillation periods is not equal, however, this does not have a significant effect on the L_B measurement. The respective errors made in measuring L_B at 99, 99.5 and 99.9% of spin compensation are 0.8, 0.4 and 0.08%. Note, in practice, it is hard to achieve 100% spin compensation due to the precision in the twist rate that can be induced. The plausible spin compensation achieved can be between 99 to 100%.

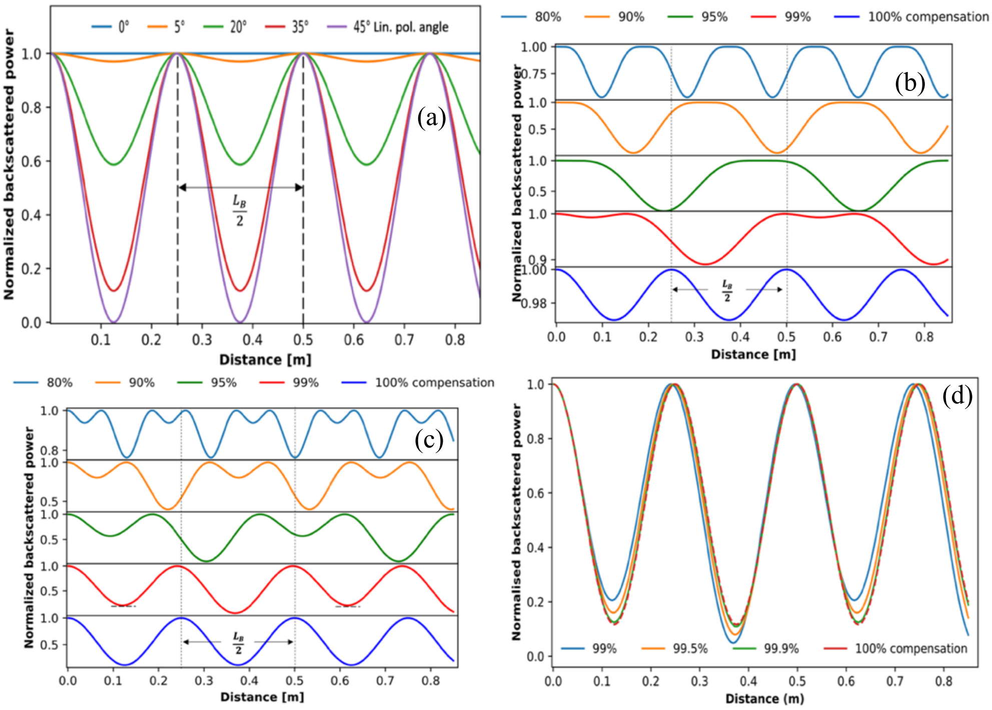

Fig. 2 (a) Effect of linear SOP azimuth, when spinning effect is completely cancelled.
(b) Effect of spinning compensation when linear SOP azimuth is 5°.
(c) Effect of spinning compensation when linear SOP azimuth is 35°.
(d) Between 99 — 100% spinning compensation when linear SOP azimuth is 35°.

Experimental results

Fig. 3 shows the experimental results of L_B measurement of a spun fibre of length 0.7 m with S_P ~8 cm (provided by the manufacturer) and an unspun fibre which is drawn from the same preform. In Fig. 3(a) the POFDR traces at three different twist rates (against spin) are shown: 9 turns (under compensates the spinning effect), 9 turns +190° (completely compensates the spinning effect) and 10 turns (overcompensates the spinning effect). It can be noticed in the case of complete spin compensation, i.e., 9 turns +190° the amplitude of oscillation periods is almost uniform. The slight deviation in the level of amplitude of the oscillation periods may be due to the non-uniform backscattering in the fibre, lack of 45° linear SOP or any residual spinning effect. The impact of latter cases on the oscillations can be noticed from the simulation results shown in Fig. 2(d). In the other two twist rates i.e., before and after complete compensation of spinning, it can be noticed that the amplitude of the oscillation periods varies significantly. This situation can be comprehended by comparing with the simulation results shown in Fig. 2(c). Note that once the spinning is completely compensated further twisting will induce the rotation of the birefringence axes again but in the direction of the twist. It can be summarized that only at a twist rate that completely cancels the spinning effect the amplitude of the oscillation periods tends to be uniform and reveals the L_B of the spun fibre. For all other twist rates before and after the complete compensation the amplitude of oscillation periods tends to vary largely. From the oscillation periods in the case of complete cancellation of spinning effect i.e., 9 turns+190°, L_B is measured as 0.31±0.01 m. The S_P deduced from the twist rate using Eq. (2) is ~7.9 cm, which agrees with the ~8 cm mentioned in the datasheet. The L_B of an unspun fibre drawn from the same preform as the spun fibre was also measured. The corresponding trace is shown in Fig. 3(b) and the L_B measured from the period of oscillation is 0.29±0.01 m. This value is in close agreement with the measured L_B of the spun fibre; thus, validating the measurement technique.

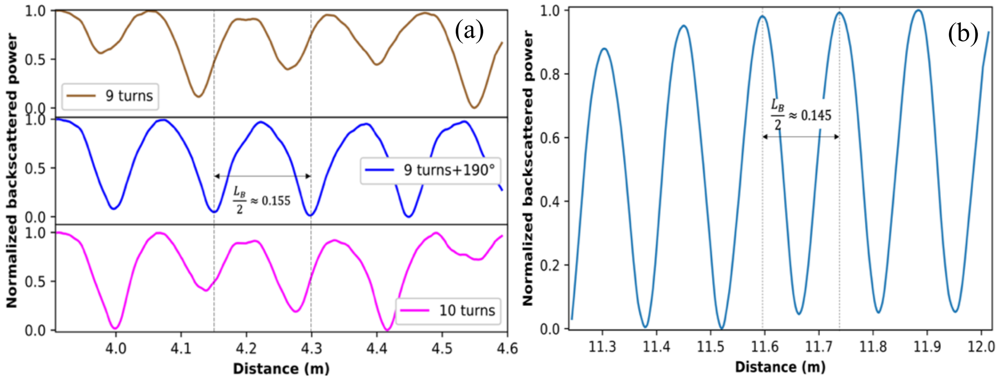

Fig. 3: POFDR trace based L_B measurement of (a) spun fibre and (b) unspun fibre drawn from the same preform

Conclusion

A measurement technique based on polarization reflectometry is provided for L_B measurement of a spun fibre with cm range S_P. The method was presented both theoretically and experimentally. Based on the discussed theory, simulation results are shown for L_B measurement under different linear SOP azimuths and various levels of spin compensation of the spun fibre. The measured L_B of the spun fibre agreed with the that of an unspun fibre drawn from the same preform. The proposed technique also provides information on the S_P of the spun fibre. The measured S_P was in good agreement with the specification. The presented results validate the proposed measurement technique.

Acknowledgement

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