Effects of ambient temperature change on polarization mode dispersion and transmission distance of slotted core NZDF ribbons

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Non-zero dispersion fiber (NZDF) ribbon cable has become an important alternative for long-haul high-speed network constructions. Since such networks require low polarization mode dispersion (PMD), it is very important to know the PMD performance of NZDF ribbon cables under different structural and environmental conditions. In particular, the ambient temperature can vary rapidly and randomly during the operation. This can cause high PMD variations in optical fiber cables. Therefore, effects of ambient temperature change on PMD should be analyzed for viability of the high-bit rate communication. In this paper, experimental results about effects of ambient temperature change on PMD characteristics of slotted core NZDF ribbon cables have been reported. Furthermore, variation of the transmission distance due to PMD variations caused by ambient temperature change has been analyzed. The ambient temperature has been changed between 10 °C and 60 °C during experiments. Measurements have been performed on two different rings formed by splicing fibers of a NZDF ribbon cable. The first ring has been formed by splicing all lateral fibers, i.e. the first and the last fibers of all 4-fiber ribbons in the cable. The second ring has been formed by splicing all central fibers, i.e. the two fibers in the center of all 4-fiber ribbons in the cable. Results exhibit a 14.2 % PMD variation with ambient temperature change for the first ring while they show a 10.7 % PMD variation for the second ring. Using experimental results it has been computed that ambient temperature change degrades maximum transmission distance of the first ring by 23.3 % and that of the second ring by 18.5 %. To simulate effects of actual field conditions on PMD variations, the NZDF ribbon cable has been exposed to ambient temperature variations from 12 °C to 26 °C for 48 hours in the field. PMD variation with ambient temperature change has been determined as 13.4 % and it has been computed that ambient temperature change degrades maximum transmission distance by 22.2 %. Experimental results reported in this paper obviously show that ambient temperature change significantly affects PMD performances of NZDF ribbons and degrades maximum transmission distances in these cables.

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1. Introduction

Non-zero dispersion fibers (NZDFs) are generally used in long-haul communication network applications where lengths of many main communication lines exceed 400 km. Polarization mode dispersion (PMD) performance of the cable is an important factor affecting the viability of the high-bit rate communication in such systems [1].

Currently, fiber ribbon cables are widely used in access networks for fiber-to-the-home (FTTH) technology [2, 3]. Therefore, there is a great interest in novel ultra-high-density fiber ribbon designs [4, 5]. However, due to their cost saving advantages and relatively easy upgradeability to 40 Gbps transmissions with respect to loose tube cables [6], slotted core fiber ribbons are also an important choice for long-haul communication networks. It is important to know PMD performances of these cables under different structural and environmental conditions for the reliability of high-bit rate communication applications. There are various papers in the literature concerning this subject [7-12].

Temperature is an important environmental factor affecting the PMD performance of optical fiber cables. Rapid and random variation of the ambient temperature during the operating regime of the fiber can cause high PMD variations. Various papers that use theoretical and/or experimental approach in focusing on evolution of PMD with the temperature have been presented for standard single mode fibers [13, 14]. However, to the best of our knowledge, there is no detailed analysis of PMD fluctuations due to temperature change in NZDF ribbons. In this work, effects of ambient temperature change on PMD characteristics of slotted core NZDF ribbon cables have been experimentally investigated. Furthermore, using the experimental results obtained, dependence of the transmission distance on PMD variations due to ambient temperature changes has been analyzed.

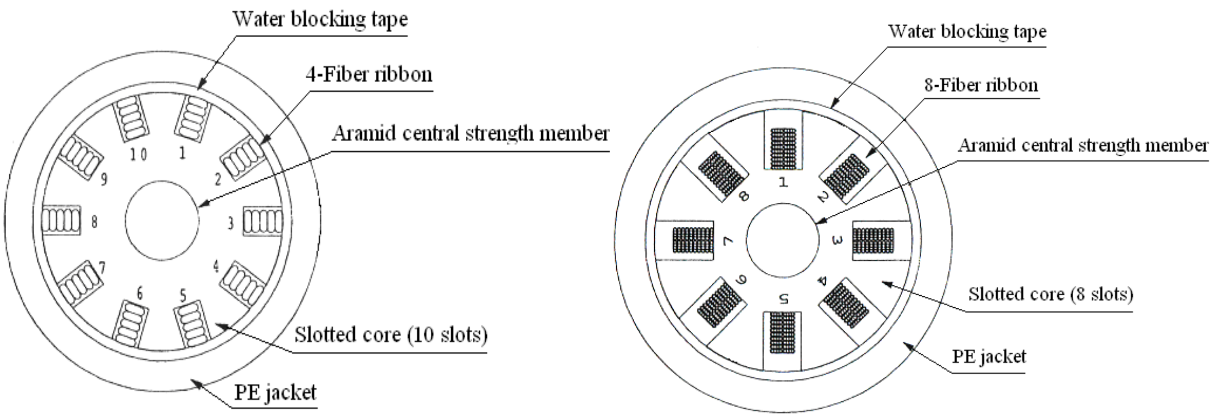
In Section 2, NZDF ribbon cable structures, methods and devices used in experiments are described. Experimental results are given and interpreted in Section 3.

2. NZDF ribbon cable structures, methods and devices used in experiments

In experiments, a reduced slope NZDF optimized for high-bit rate transmission in a wavelength range of 1530 - 1625 nm has been used. Some optical and geometrical characteristics of this fiber are shown in Table 1.

Table 1. Optical and geometrical characteristics of NZDF

Parameter	Value
Chromatic dispersion (1530 - 1565 nm)	2.6 - 6.0 ps/nm.km
Chromatic dispersion (1565 - 1625 nm)	4.0 - 8.9 ps/nm.km
MFD (1550 nm)	8.4 ± 0.6 μm
Cladding diameter	125± 1.0 μm
Core/cladding concentricity error	≤ 0.6 μm
Cladding non-circularity	≤ 1.0 %



(a) (b)

Fig. 1. a) Structure of Cable 1 (200-fiber, 10 slots, 5 layers of 4-fiber ribbons) and b) Structure of Cable 2 (640-fiber,8 slots, 10 layers of 8-fiber ribbons)

Two different types of slotted core NZDF ribbon cables have been used. Cable 1 is a 200-fiber cable with 10 slots containing 5 layers of 4-fiber ribbons in each slot. Cable 2 is a 640-fiber cable with 8 slots containing 10 layers of 8-fiber ribbons. Both cables have Aramid strength members and they have prevented from water penetration by water blocking tapes. Structures of sample cables are shown in Fig.1 and their geometrical parameters are given in Table 2.

Generally, PMD is measured under fixed temperature values. However, the actual temperature is not fixed and can vary rapidly and randomly. Therefore, the birefringence and the mode coupling along the cable vary continuously and randomly under actual environmental conditions. This can cause higher PMD variations in optical fiber cables under real field conditions with respect to fixed temperature experiments.

To observe this effect, using lateral and central fibers in all ribbons of Cable 1 wound on a wooden drum, two separate rings have been formed. Lateral fibers in a 4-fiber ribbon are the first and the last fibers of the ribbon, i.e. Fiber 1 and Fiber 4, while central fibers in a 4-fiber ribbon are two fibers in the center of the ribbon, i.e. Fiber 2 and Fiber 3. The ring formed with lateral fibers of all ribbons will be called as the first ring while that formed with central fibers of all ribbons will be called as the second ring throughout the paper. Each ring has an approximate length of 47 km. Using Jones matrix method based PAT9000F PMD/PDL analyzer and Agilent 81640A laser, PMD values of both rings have been measured with 30 minutes intervals in 1550 nm wavelength range. The ambient temperature has been varied from 10 °C to 60 °C during the total experiment time as shown in Fig. 2.

Table 2. Geometrical parameters of sample cables

	Cable 1	Cable 2
Fiber count	200 fibers	640 fibers
Ribbon type	4-fiber	8-fiber
Ribbon thickness	0.4 mm	0.3 mm
Ribbon width	1.1 mm	2.1 mm
Strength member diameter	4.5 mm (A-FRP)	4.5 mm (A-FRP)
Jacket thickness	1.5 mm	1.5 mm
Cable outer diameter	17 mm	22 mm
Water prevention	WB tape	WB tape

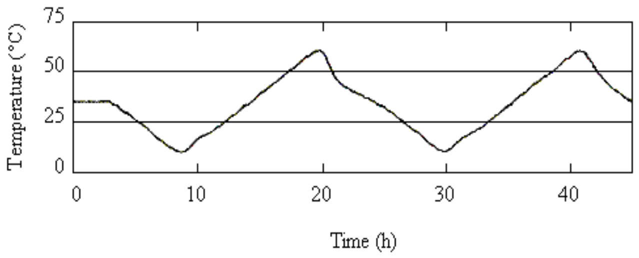


Fig. 2. Temperature variation during the total experiment time

Three additional experiments have been performed in order to investigate the PMD performance of fiber ribbon cables under actual field conditions in details. These experiments are controlled room temperature, uncontrolled room temperature and field simulation experiments. In all three experiments, PAT9000F PMD/PDL analyzer and 1550 nm Agilent 81640A laser have been used and the PMD value of the cable has been measured with 30 minutes intervals.

In the controlled room temperature experiment, the fiber cable wound on a wooden drum has been kept in a room for 24 hours whose temperature was constant at 23 °C. In the uncontrolled room temperature experiment, fibers of Cable 1 wound on a wooden drum have been spliced to form a ring with a length of 50 km and the cable has been kept in a room for 24 hours whose temperature varied by +/- 4 °C. In the field simulation experiment, fibers of Cable 2 have been spliced to form a ring with a length of 60 km and the cable has been laid on the ground and exposed to ambient temperature variations for 48 hours in the field in order to simulate effects of actual field conditions on PMD variations. The ambient temperature has varied approximately from 12 °C to 26 °C during the experiment.

3. Experimental results

PMD variations observed in the first and second rings of Cable 1 for the case at which the ambient temperature has been varied from 10 °C to 60 °C as shown in Fig. 2 are given in Figs 3 and 4, respectively.

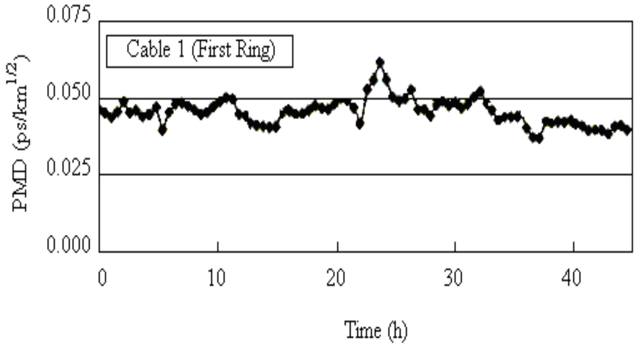


Fig. 3. Variation of PMD with ambient temperature change observed in the first ring of Cable 1

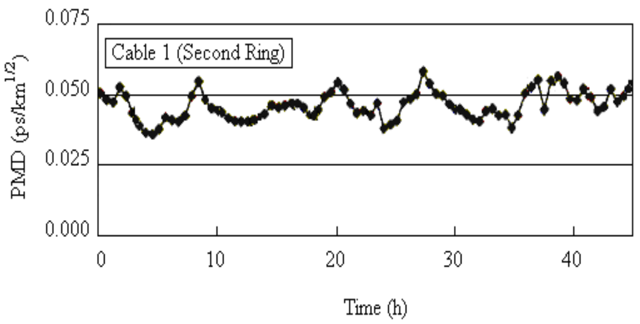


Fig. 4. Variation of PMD with ambient temperature change observed in the second ring of Cable 1

In Figs. 3 and 4, it is obvious that the temperature change causes variation in PMD values of the fiber ribbon cable. Distribution of PMD values in both rings obtained during ambient temperature change are shown in Figs. 5 and 6.

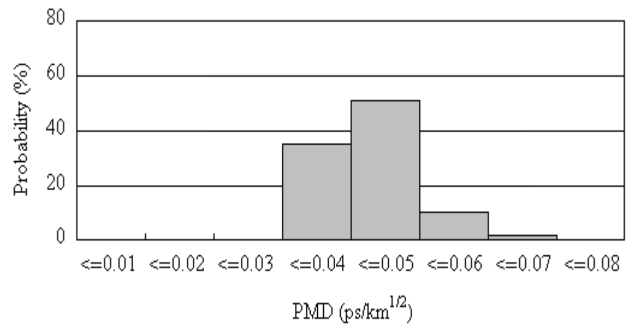


Fig. 5. Distribution of PMD values in the first ring of Cable 1

In the first ring, the average PMD is 0.044 ps/km$^{1/2}$ and variation of PMD with ambient temperature change is 14.2 %. In the second ring, the average PMD is 0.047 ps/km$^{1/2}$ and variation of PMD with ambient temperature change is 10.7 %.

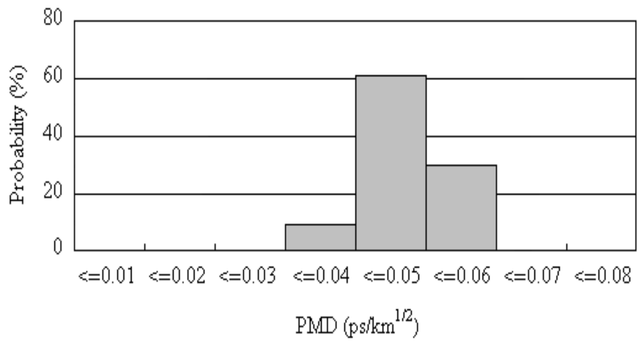


Fig. 6. Distribution of PMD values in the second ring of Cable 1

The reason of the difference between PMD performances of the first and second rings is that the first ring formed by lateral fibers is more likely to be exposed to fiber-cable interactions with respect to the second ring formed by central fibers that are protected from such interactions by lateral fibers. Thus, the birefringence and the mode coupling occurring along the cable have more significant effects on the first ring comparing with that on the second ring.

For a 1 dB power penalty, allowable PMD can be calculated with [15],

$$L = \left[\frac{10^3 f}{B \, x \, PMD} \right]^2 \qquad (1)$$

where *L* is the transmission distance in terms of km, *f* is the allowable bit-period fraction and *B* is the bit-rate in terms of Gbps.

Assuming L = 400 km, f = 0.1 and B = 40 Gbps, (1) gives a maximum PMD value of 0.125 ps/km$^{1/2}$. Comparing instantaneous PMD values shown in Figs.3 and 4 with computed value, it can be concluded that first and second rings of Cable 1 will be able to support 40 Gbps transmission of a 400-km network to a high extent.

Let's interpret the results for maximum transmission distance.

Using the above experimental results obtained for the first ring and assuming f = 0.1 and B = 40 Gbps it can be computed from (1) that

a) for average PMD value of 0.044 ps/km$^{1/2}$, maximum transmission distance is 3228 km.

b) with effect of ambient temperature change on PMD, maximum transmission distance will be 2475 km.

Ambient temperature change degrades maximum transmission distance of the first ring by 23.3 %.

Using the above experimental results obtained for the second ring and assuming f = 0.1 and B = 40 Gbps it can be computed from (1) that

a) for average PMD value of 0.047 ps/km$^{1/2}$, maximum transmission distance is 2830 km.

b) with effect of ambient temperature change on PMD, maximum transmission distance will be 2310 km.

Ambient temperature change degrades maximum transmission distance of the second ring by 18.5 %.

In the controlled room temperature experiment, a very stable PMD performance with only a slight variation of 2.2 % has been observed as expected while in the uncontrolled room temperature experiment, a more significant PMD variation, i.e. 9.7 %, has occurred.

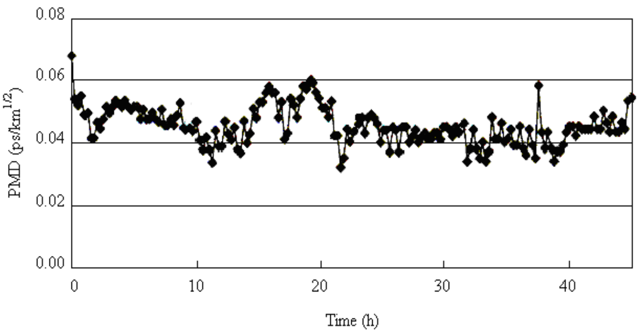


Fig. 7. Variation of PMD with ambient temperature change for Cable 2 observed in field simulation experiment

Variation of PMD with ambient temperature change in the field simulation experiment is shown in Fig. 7 and distribution of PMD values obtained during the experiment is given in Fig. 8. The average PMD is 0.045 ps/km$^{1/2}$ and variation of PMD with ambient temperature change is 13.4 %. Comparing instantaneous PMD values shown in Fig. 7 with maximum PMD value computed from (1), it can again be concluded that Cable 2 will be able to support 40 Gbps transmission of a 400-km network to a high extent.

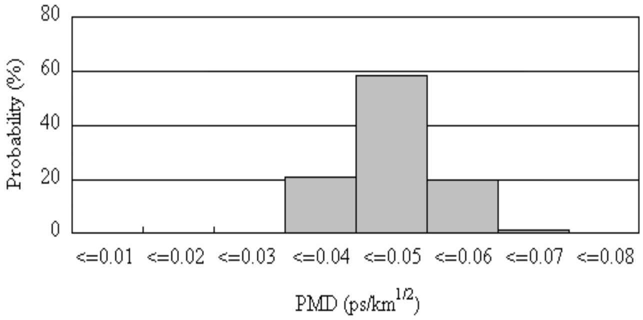


Fig. 8. Distribution of PMD values for Cable 2 in field simulation experiment

Let's again interpret the results for maximum transmission distance.

Using results of the field simulation experiment and assuming f = 0.1 and B = 40 Gbps it can be computed from (1) that

a) for average PMD value of 0.045 ps/km$^{1/2}$, maximum transmission distance is 3086 km.

b) with effect of ambient temperature change on PMD, maximum transmission distance will be 2400 km.

Ambient temperature change degrades maximum transmission distance by 22.2 %.

Results obtained from Cable 2 in the field simulation experiment are in good agreement with that of experiments performed on Cable 1.

4. Conclusion

In this paper, results of the experimental investigation about effects of ambient temperature change on PMD characteristics of slotted core NZDF ribbon cables have been reported. Furthermore, variation of the transmission distance due to PMD variations caused by ambient temperature change has been analyzed.

In the experiment where ambient temperature has been changed between 10 °C and 60 °C, the average PMD and variation of PMD with ambient temperature change have been determined as 0.044 ps/km$^{1/2}$ and 14.2 %, respectively for the first ring formed by splicing lateral fibers of a NZDF ribbon cable. For the second ring formed by splicing central fibers of the same cable, the average PMD and variation of PMD with ambient temperature change have been determined as 0.047 ps/km$^{1/2}$ and 10.7 %, respectively. The difference between PMD performances of the first and second rings is due to fiber-cable interactions which result in more significant birefringence and mode coupling effects on lateral fibers with respect to central fibers. Using the experimental results it has been computed that ambient temperature change degrades maximum transmission distance of the first ring by 23.3 % and that of the second ring by 18.5 %.

In the experiment performed to simulate effects of actual field conditions on PMD variations, the ring formed by splicing all fibers of a NZDF ribbon cable has been laid on the ground and exposed to ambient temperature variations for 48 hours in the field. During the experiment, the ambient temperature has varied approximately from 12 °C to 26 °C. The average PMD and variation of PMD with ambient temperature change have been determined as 0.045 ps/km$^{1/2}$ and 13.4 %, respectively. Using the experimental results it has been computed that ambient temperature change degrades maximum transmission distance by 22.2 %.

Results obtained in the field simulation experiment are in good agreement with that of the experiment performed on first and second rings of the NZDF ribbon cable where the ambient temperature has been changed between 10 °C and 60 °C. It is also obvious that the correlation between the temperature variation and the PMD variation is not direct. This is due to the stochastic nature of PMD. Subjecting the ribbon cable to rapid temperature changes gives rise to time varying stresses along the cable length. Those time varying stresses alter the PMD values. Experimental results show that ambient temperature change significantly affects PMD performances of NZDF ribbon cables and subsequently degrades maximum transmission distance of the cable.

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