Outdoor atmospheric influence on polarization mode dispersion in optical cables

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Abstract

Oscillation of phenomena birefringence under atmospheric conditions is reported. Paper contains measured values of polarization mode dispersion from long term monitoring scenario and gives illustration about measuring of long time installed cables. Several commonly utilizing measuring techniques were used to determine birefringent properties of the fibers. Results are correlated with temperature changes during different terms to achieve proper comprehensive conception of progress.

1. Introduction

With new transmitted formats and modulations in optical communications and sensor networks, Polarization Mode Dispersion (PMD) has become very important parameter with significant impact to transmission capacity. For high bit rate transmissions with long reach ability, it is necessary to keep Differential Group Delay (DGD) low and thus it desires watching of PMD parameter and PMD coefficient which determine statistical distribution of DGD. The distribution is then presented for whole fiber length by PMD coefficient. In order to determine random behavior of birefringence there is requirement for long term PMD monitoring and the longer monitoring setup the more precise results are obtained. Long-term measurement of PMD was theoretically described in 2000 by M. Karlsson [1], who used the Jones matrices and statistical evaluation DGD. However during high PMD fibers measuring it is also required to define hazardous areas, containing high PMD sections, which can have fatal impact to accuracy and also to transmissions characteristic. For this purpose, the Polarization Optical Domain Reflectometer (POTDR) method was developed [2]. The method facilitates precise location of the mentioned sections which gives good tool for optical network infrastructure development and supervising.

According to recommendation ITU-T G.652[3] the longest distance for 40 Gbit/s system can be 80 km in case of PMD coefficient 0.2 ps/km$^{1/2}$ while it is decreased even up to 2 km for PMD around 0.5 ps/km$^{1/2}$. The random behavior of birefringence in installed cables comes most frequently with temperature and wavelength changes. In 2003, M. Brodsky presented papers on the optimal path length, measured to evaluate PMD[4], which concluded that some of the fibers can be characterized during the one week while a so called "live" fibers require characterization measurements over months or years. Poggiolini [5] performed 73-days' measurement metropolitan area networks in Turin, stating that the changes DGD are inherently limited due to the daily cycle and entire period. The impact of temperature to the cables was well discussed in [6]. Despite of recent made fibers and cables, old produced fibers have been still utilized within networks which have not had accurate PMD quality control. In the time of their installation, such parameters were not required. One have to take in consideration potential aging of photonics structures[7] which can be evoked by high optical powers and as well their possible damaging[8]. The paper presents comparison of commonly used PMD measuring methods and their validation during different terms in aged fiber structure. First results of atmospheric influence on PMD statistics measured in unique measuring polygon are published.

2. Measurement setup

In order to ensure real transmission characteristic for optical fibers and cables, a measuring polygon was designed and placed on the roof of Czech Technical University in Prague, Faculty of electrical engineering (see Fig. 1a). The scheme is involved for long term monitoring of transmission characteristics under environmental conditions such temperature, pressure, humidity or wind. For easy access to polygon its switch was placed to the optical laboratory. To achieve proper information about instant weather changes, two meteorological stations recording the temperature, humidity, atmospheric pressure, precipitation, rain intensity and the speed and direction of the wind were also placed on the roof of university campus. These stations' positions (A, B) with testing polygon (C) are shown in Fig.1.

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Figure 1. Testing polygon: a) roof of CTU building b) Alcatel cable c) optical terminal

Cables, purposed for monitoring, were precisely selected especially because of containing of high PMD sections. The sections were at first characterized by P-OTDR measuring. Fibers within the cables originate from 1994 and they had been primary used for metropolitan optical network in Prague subway under different conditions. These fibers have not ever been investigated through PMD measuring or observing. Polygon setup consists of two same Alcatel cables containing 72 fibers within 6 tubes. Each cable is approx. 500 m long, welded together in the connection box placed also outside. Total length of links is then approx. 72 km, divided to four sections with lengths 12 and 24 km respectively. Sections are formed from separated tubes within cable to maintain consistent conditions. Measurement setup is shown in Fig. 2.

All 12 fibers in each tube were welded together so that each link passes 12-times through all circuit along the building wedge. In addition, the whole circuit is formed by 6 smaller circuits including different conditioned areas such as shadows, shielding and nearness electronic devices like an air condition, etc. Structure of cable and measurement scheme is described in Fig. 2.

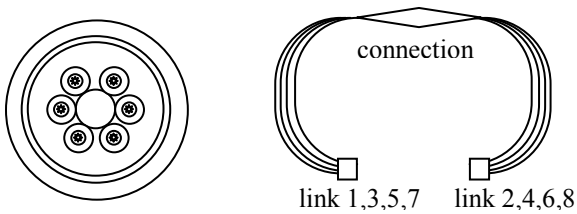

Figure 2. Measurement scheme: a) cable profile; b) optical links

We carried out initial measurements with different commonly used methods such interferometry (Traditional Analysis Interferometry – TINTY and General Analysis Interferometry – GINTY)[9], Scrambled State-of-Polarization Analysis (SSA)[10] and POTDR[11] on wavelengths 1520-1627 nm. Since the random behavior of birefringence and using different techniques then we have obtained relative high range of total PMD. In order to avoid mistakes with length mismatch of the cables, we investigated PMD coefficient applied to fiber length and contributions in each section were observed by POTDR. We assume the distances $L > 1$ km to ensure the PMD coefficient can be determined in terms of $km^{1/2}$[12].

With assuming propagation constants in two orthogonal principle axes β_x and β_y at wavelength ω, these constants are different due to birefringence[13]:

$$\Delta\beta = \left(\beta_x - \beta_y\right) = \frac{\omega}{c}\Delta n_{eff} , \tag{1}$$

where Δn_{eff} refers to differential effective refractive index for the two modes. Relative group delay (referred as DGD) between two orthogonal polarization modes for fiber length L is expressed by:

$$\Delta\tau_g = \frac{L\Delta n_{eff}}{c} . \tag{2}$$

Differential Group Delay round trip in position z, used in PMD distributed measurement, is therefore computed as follows[14]:

$$DGD_{RT}^2\left(z\right) = \frac{1}{\delta\omega^2}\alpha_{dT}\Delta T_{ms} , \tag{3}$$

where $\delta\omega^2$ is relative wavelength spacing, α_{dT}^2 relative scrambling factor and ΔT_{ms} is mean-square value of number of wavelength differences.

3. Results

Measuring scheme contains older fibers which were historically (as can be case of majority of older laid infrastructures) tested mainly only over attenuation and Chromatic Dispersion (CD). To the authors best knowledge these parameters of the fibers to date have not experienced any detrimental changes. Despite of well-known random PMD oscillation influenced by stressed conditions, we characterized how these conditions, especially temperature, could influence long term PMD measurement with several measuring techniques.

This paper presents first demonstrations of PMD measurements at CTU polygon using different techniques described above. Fibers tests results are from April 2013 till January 2014. Root Mean Square (RMS) value was calculated to determine PMD coefficient. Then the variance of PMD coefficient, displayed in *y*- axes, was computed from RMS of the each measured value. The links were tested from both ends and they are designated as follows: four fibers with marked ends (link 1,2; link 3,4; link 5,6 and link 7,8). Table 1 contains PMD_{RMS} values for all links. Figure 3 represents RMS differences for two 12-km links and Figure 4 compares remaining two 24-km links.

Table 1. PMD values of the links

link:	1	2	3	4	5	6	7	8
PMD_{RMS}[ps]	0.758	1.028	4.968	5.131	3,44	3.194	7.074	6.820
$PMD_{coeff\text{-}RMS}$[ps/km$^{0.5}$]	0.232	0.243	1.419	1.460	0.742	0.661	1.462	1.419

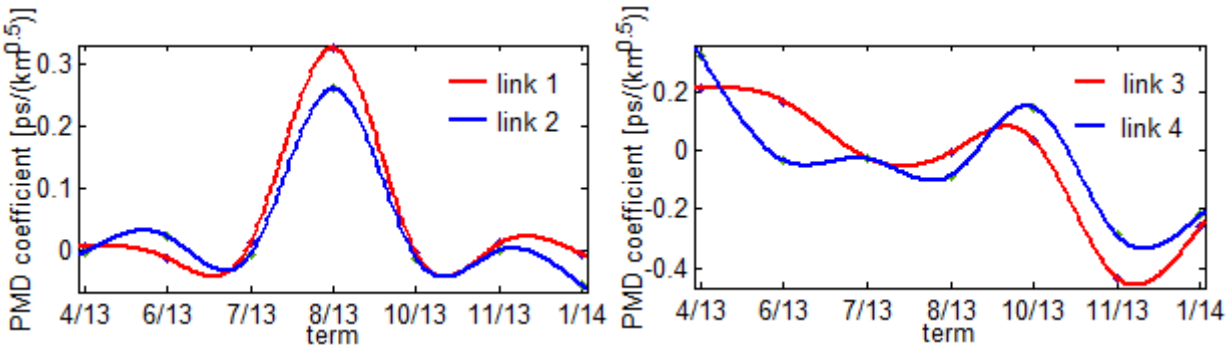

Figure 3. RMS difference: a) first 12 km links; b) second 12 km links

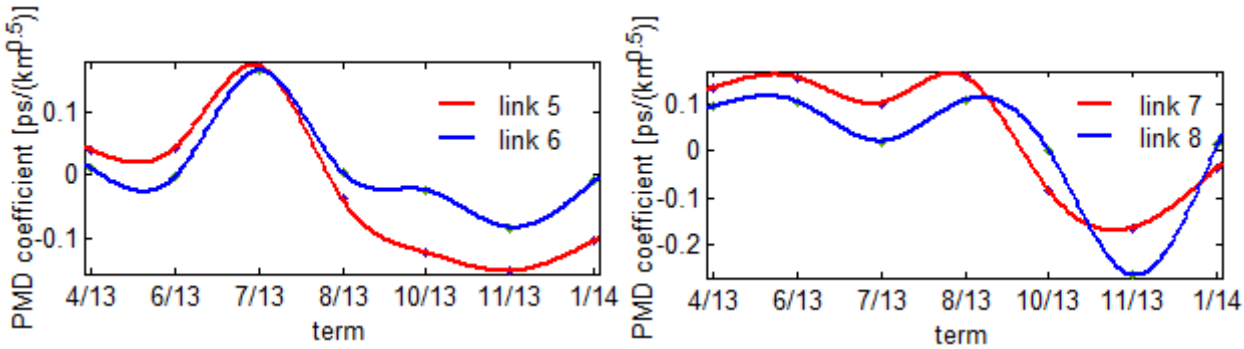

Figure 4. RMS difference: a) first 24 km links; b) second 24 km links

Results show fluctuations of PMD coefficient during measuring terms. We have observed fluctuations up to almost ±0.3 ps/km$^{1/2}$. It mostly comes from not-uniformed distribution of cumulative DGD along fibers. It seems that hazardous sections behave much different under the stressed conditions. The distribution of cumulated PMD was investigated by POTDR method. We have observed increased PMD in hazardous section (see peak in Fig.4a) which caused almost 20 % of all PMD in only 967 meters while some low PMD sections indicate invariable progress. After that, the oscillations of all links were correlated with temperature - see Fig. 5.

Measured temperature highly correlates with oscillation of PMD coefficient but the temperature has one but not the only impact to DGD results. Although the all fibers originate from one developer and they are clustered in one optical cable, the particular components evince very different behavior, especially in PMD point of view. A lot of splices also contribute to ambiguous results. More measured results will be available by term of the conference.

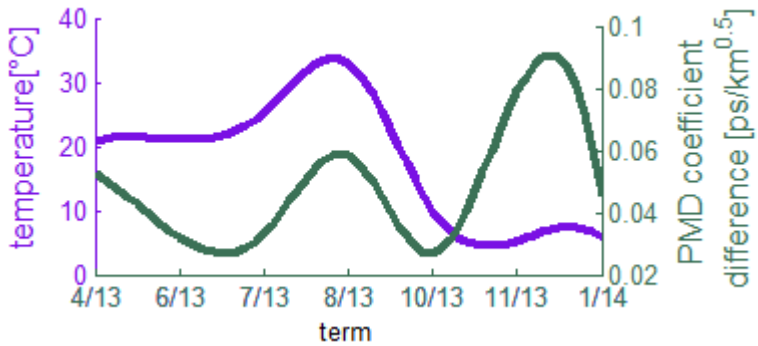

Figure 5. Thermal changes vs. PMD difference

5. Conclusion

The paper discussed various measuring accuracy of birefringence phenomena with aiming to long time statistics observed on installed fibers. PMD features were monitored in harsh environment. First results from measuring polygon indicate fluctuations of PMD with thermal changes along optical fibers up to 1 ps for 12 km link and 1.8 ps for 24km link respectively and fluctuating of PMD coefficient up to 0.3 ps/km$^{1/2}$. When considering PMD recommended limits for 40 Gbit/s systems or higher, such numbers exceeded the limits more than three times in particular links. This could be together with continuing oscillations of birefringence due to aging of the structure crucial for optical infrastructures. From several tested PMD measuring methods, the best way for next PMD monitoring of aged infrastructure revealed to a combination of accurate and distributed measuring. To further validate results over seasonal weather influences a long term measuring campaign has been set at Czech Technical University in Prague.

6. Acknowledgments

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