The impacts of temperature on PMD and CD dispersions during high speed optical communications

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***Abstract* — The widespread use of optical fiber networks caused expansion of 10 Gbits and 40 Gbits transmission. These new requirements caused negative impacts like chromatic dispersion (CD) and polarization mode dispersion (PMD). CD and PMD must be measured more accurately and frequently than ever. In this paper both dispersions for 25 km long singlemod fiber in temperature range from -35˚C to 60˚C were measured and discussed. Results show that there is a high impact of temperature on measured parameters of the dispersions.**

***Index Terms* — Optical fibers, optical fiber dispersion, chromatic dispersion, polarization mode dispersion**

I. INTRODUCTION

Dispersion causes different transmitted signal components which are traveling at different speeds. Dispersion has pulse widening as end result, which certainly creates great transmission speed limit through fiber and also fiber length limit, because it limits shortness of the pulse that can be sent and successfully received on the other end of the fiber [1]. Time elongation can lead to pulse overlapping, which affects on signal-noise ratio (SNR). On the other side, as pulse travels for a longer time it wideness more, meaning that the dispersion reduces directly fiber speed-length product. Major dispersion mechanisms are ***chromatic dispersion*** (CD) and ***polarization mode dispersion*** (PMD).

Light pulse from light source contains certain wavelength spectrum, for example laser diodes can emit spectrum 1 nm wide. Refraction index is not the same for all wavelengths, which implicates that different wavelength within one optical pulse will travel at different speeds. That will cause components at different wavelengths not arriving simultaneously on the other end of the fiber. This phenomenon has known as *chromatic dispersion* or just *dispersion* [2].

Polarization mode dispersion (PMD) derives from the fact that light at certain wavelength in fact occupies two separate polarization modes. At the beginning, these two modes are adjusted in relation with each other, however with time every mode starts to propagate independently, which leads to modes not being adjusted anymore. Differences in propagation of modes derive from stated here: fiber is not ideally uniform throughout its length, cross section is not ideally round, refraction index is not equal at every cross section (called birefringence), various external factors as temperature changes, mechanical bending, and strokes.

All of this leads to every mode having different refraction index in front of it, and because of that moving at different velocity, and light polarization vector will rotate. Created time difference between polarization modes will lead to pulse widening. Since the difference between polarization indexes is insignificant and dispersion value by itself is small, usually its value is around 0.05 $ps/\sqrt{km}$. While chromatic dispersion has statistic nature and it grows with square length of fiber, it represents limiting factor to very long fibers on high transmission velocities.

II. MEASUREMANTS EQUIPMENT

For all measurements was used EXFO FTB 5700 Single-Ended Dispersion Analyzer (Fig 1) which combines chromatic dispersion and polarization mode dispersion measurement [3].

Figure 1 FTB 5700 Single-Ended Dispersion Analyzer

III. MEASURING TEMPERATURE DEPENDENCE OF CHROMATIC AND POLARIZATION DISPERSION

These measurements which are taken, point at temperature impact on polarization mode and chromatic dispersion. To realize this experiment, we used fiber that is wounded on coil and placed in device with artificial atmosphere (Fig 2).

Figure 2 Optical fiber coil in device with artificial atmosphere

First, we cooled down fiber to -35 ºC temperature, and then raised temperature with step of 5 degrees, until end temperature of 40 degrees, and then with step of 10 degrees until 60 degrees.

It can be noticed that coefficient and chromatic dispersion value on 1550 nm do not have great change, but at the same time reduction of both values is clearly expressed with temperature growth. Maximal chromatic dispersion, in this case is 1630 nm, because the slope is continuously positive, changes with temperature.

All graphs which are related to PMD have a clear tendency to grow, and we observe them, relative change of PMD value is more significant. Total PMD changes from 0.3 ps to 0.43 ps, which is 45 % growth, while chromatic dispersion changes from 438.06 ps to 432.91 ps which is just 1 % change. On the other side, if absolute values of PMD are observed, it has total change of just 0.013 ps, while change of CD is 5.15 ps, which are certainly incomparable quantities. It's very important to note that these measurements are realized in laboratory conditions, and that real field measurements would give surely different results, especially for PMD. Most probably general growth and reduction trends would still remain, and concrete values of CD also would probably remain the same. While concrete values for PMD would be significantly higher, total change would maybe be similar with change of CD.

TABLE I. MEASUREMENT RESULTS FOR CHROMATIC DISPERSION

Temp [˚C]	CD (λ=1550) [ps/nm]	Slope [ps/(nm²·km)]	Coefficient change CD(λ=1550) [ps/(nm·km)]	Max. Dispersion [ps/nm]
-35	438.06	0.0584	16.36	550.38
-30	437.53	0.0575	16.34	548.10
-25	437.01	0.0573	16.32	547.08
-20	436.06	0.0587	16.28	548.92
-15	435.27	0.0561	16.25	543.10
-10	436.08	0.0584	16.28	548.34
-5	434.83	0.0591	16.24	548.48
0	434.65	0.0574	16.23	545.05
5	435.56	0.0580	16.26	547.00
10	435.55	0.0597	16.26	550.20
15	435.34	0.0572	16.26	545.24
20	435.83	0.0573	16.27	545.99
25	434.53	0.0582	16.22	546.49
30	434.44	0.0585	16.22	546.81
35	433.85	0.0578	16.20	544.97
40	433.58	0.0575	16.19	544.07
50	433.39	0.0586	16.18	546.05
60	432.91	0.0599	16.16	547.98

It should be noted that measurement at 1550 nm wavelength is a standard for this type of fiber [4]. Slope is also standard parameter and it is result of the fact that chromatic dispersion function in terms of wavelength is always linear. Measured parameters are represented in Table I , Table II and Figures from 3 to 9.

TABLE II. MEASUREMENT RESULTS FOR POLARIZATION MODE DISPERZION

Temp	PMD:[ps]	PMD coefficient [ps/sqrt(km)]	Second order PMD[ps/nm]
-35	0.3	0.0571	0.0396
-30	0.3	0.0583	0.0413
-25	0.31	0.059	0.0423
-20	0.35	0.0682	0.0564
-15	0.31	0.0605	0.0445
-10	0.32	0.0627	0.0478
-5	0.34	0.0665	0.0537
0	0.34	0.0661	0.0531
5	0.38	0.0732	0.0651
10	0.36	0.0704	0.0602
15	0.40	0.0773	0.0726
20	0.38	0.0743	0.067
25	0.34	0.066	0.0529
30	0.37	0.0714	0.062
35	0.39	0.0749	0.0683
40	0.42	0.0806	0.079
50	0.32	0.0617	0.0462
60	0.43	0.083	0.0837

On Figures 3,4,5 and 6 are shown parameters of chromatic dispersion.

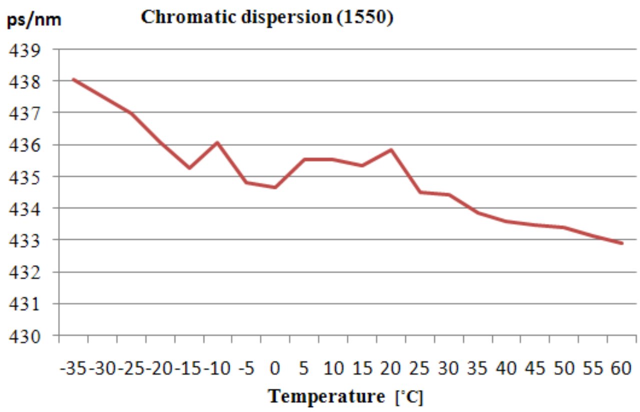

Figure 3 Graph of chromatic dispersion change with temperature growth

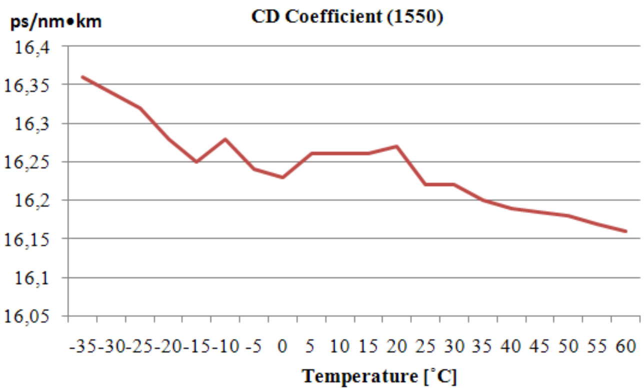

Figure 4 Graph of chromatic dispersion coefficient change

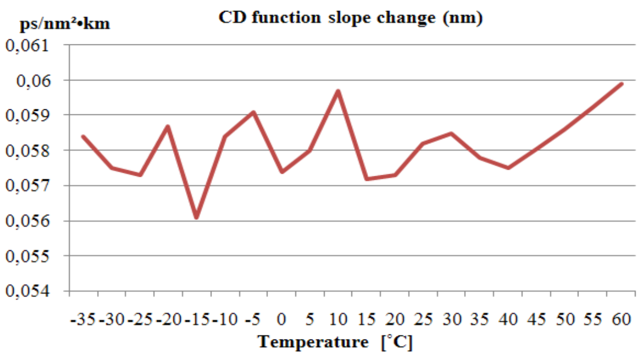

Figure 5 Graph of chromatic dispersion function slope change

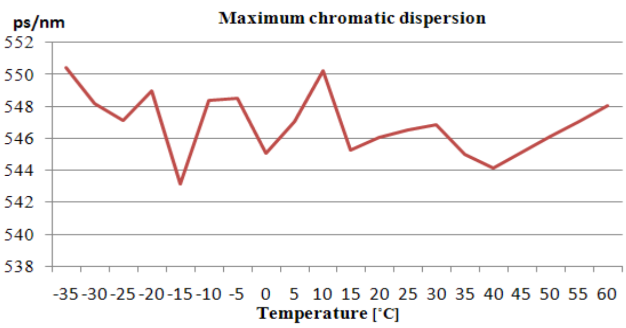

Figure 6 Graph of maximal chromatic dispersion value change in the measuring range

On Figures 7,8 and 9 are shown parameters of polarization mode dispersion.

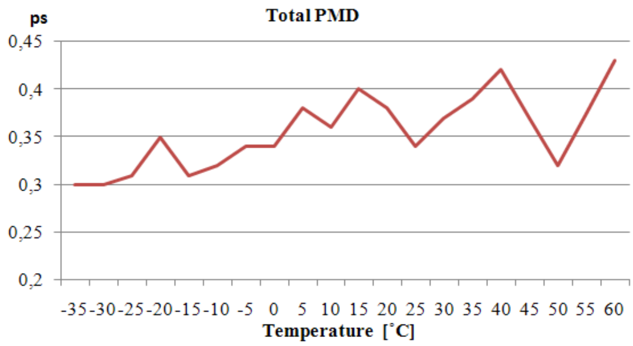

Figure 7 Graph of polarization mode dispersion value change with temperature growth

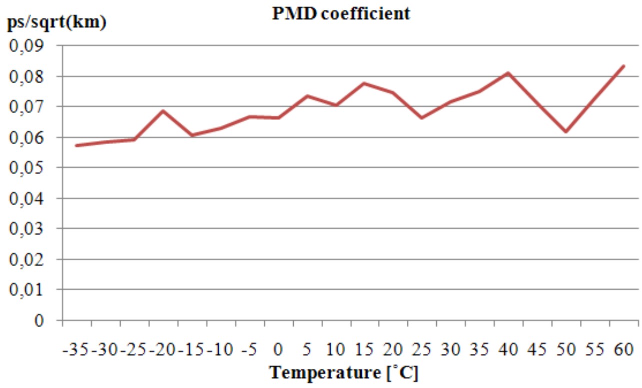

Figure 8 Graph of polarization mode dispersion coefficient change

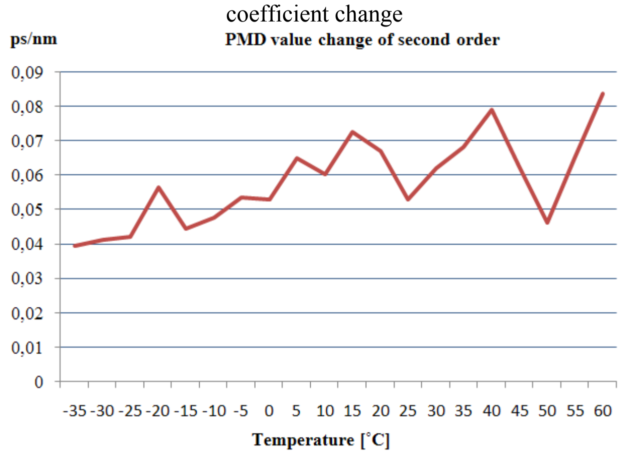

Figure 9 Graph of polarization mode dispersion value change of second order

If we give a bit closer look to the graphs of PMD, we will notice that function is not monotonous rising, but it has a few local minimums, one of which is most extreme at the 50 ºC temperature. This kind of result is completely in accordance to basic theoretical assumption that PMD is accidental and it has a statistic nature. Changes are unpredictable and sudden, so it's very hard to control them. That's why PMD requires real time compensation. CD function at 1550 nm is more monotonous than first one, although it also has a few local minimums which are not so extreme here. We can predict chromatic dispersion value a lot easier, and also predict how it is going to change eventually, which significantly simplifies its compensation. Compensation of CD must be implemented for some certain concrete value on the link, which means that it does not have to be real time, and that fact lowers costs.

IV. CONCLUSION

It was shown that CD and PMD depend on temperature changes. CD is lower on higher temperatures, and difference between value on -35 ºC and 60 ºC is significant. PMD has less impact on lower temperatures but it has much rapid changes then CD. The experiment would surely have been better if executed for more fiber types, and many of the same types of different length, different manufacturers. Such results would be far significant, and could be deeper to understand the nature of these processes and bring more secure conclusions about the temperature depending CD and PMD.

ACKNOWLEDGMENTS

This paper is part of the project “Development of systems and instruments for investigation water, oil and gas”, TR 11006. Project has been carried out with the financial support of the Ministry of Science and Technological Development of the Republic of Serbia, to which authors are very grateful.

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