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Pressure Sensor Based On Optical Fiber With Reduced Coating Diameter

Abstract. *In this paper the idea of Pressure Sensor Based On Optical Fiber With Reduced Coating Diameter PSOFD is described.Developed pressure sensor involves Lateral Loading Method used in microbending tests. Besides Optical Fiber With Reduced Coating Diameter OFRCD two types of SMF were tested: 1) standard SMF described in G.652.D recommendation, 2) bend insensitive SMF with nanostructure ring in cladding described in G.657.B recommendation. This paper presents the obtained results of research and the discussion.*

Streszczenie. *W artykule przedstawiona została idea światłowodowego czujnika nacisku opartego na włóknach o zredukowanych pokryciach pierwotnych. Wykonany czujnik nacisku wykorzystywał metodę obciążenia bocznego używaną w testach mikrozgięciowych. Dodatkowo w światłowodowym czujniku nacisku przetestowano dwa inne światłowody: 1) SMF opisany w rekomendacji G.652.D, 2) SMF zawierający Nanostruktury w płaszczu opisany w rekomendacji G.657.B.* ***Światłowodowy czujnik nacisku oparty na włóknach o zredukowanych pokryciach pierwotnych***

Keywords: optical pressure sensor, optical fiber, reduced coating diameter, Lateral Loading Method
Słowa kluczowe: światłowodowy czujnik nacisku, światłowód, zredukowane pokrycie pierwotne, test obciążenia bocznego

doi:10.12915/pe.2014.11.31

Introduction

Fiber optic sensors are insensitive to electromagnetic interference EMI, they are small, light and relatively cheap [1,2]. The structure of standard single mode optical fibers SMF made of glass is well known. Standards define primary coating diameter as 242-250 µm in circular cross-section, but the need for miniaturization of fiber optic cables necessitates the development of new solutions.

In 12/2012 new recommendation 60793-2-50 ed4 was published by IEC. It introduced new type of bend insensitive Optical Fiber with Reduced Coating Diameter (OFRCD) to 200µm. Reduced coating should give us an opportunity of sensing the pressure better.

In this paper, three types of SMF were tested: 1) standard SMF described in G.652.D recommendation, 2) bend insensitive SMF with nanostructure ring in cladding described in G.657.B recommendation and 3) bend insensitive SMF with coating diameter reduced to 200µm described in IEC 60793-2-50 ed4 recommendation.

Protective layers of optical fiber

An essential requirement for optical fiber primary coating is to protect against microbending and constant load. This requires the cured coating of constant thickness located concentrically around the fiber in a continuous manner _ over the entire length of the optical fiber. This coverage must be resistant to abrasion and moisture. Appropriate thin coatings consistently need to have a stable viscosity (minimum 6 months), adhere well to glass, have low surface tension, be free from contaminants, have a minimum generation of hydrogen atoms (10-2 - 10-4 µl/g) and enable rapid cure . It is further expected that the cured coating will have a permanent elasticity and adhesive properties within 25 years of work of the installed cable. [3,4]. The most popular types of coatings for optical glass fibers are shown in Table 1 [5,6].

Optical Fiber with Reduced Coating Diameter

Such optical fibers must be compatible with the existing solutions. Maintaining the match between the different types of fibers requires compliance with the standard of the glass diameter, i.e. core and its cladding, which is 125µm. Coating of the optical fibers consists of two layers: primary and secondary coating.

Table 1. Popular coating types used for glass optical fibers

Type coating	Operating temperature	Characteristic	Main application
Acrylic	≤80ºC or>150ºC	easy to remove, eco unfriendly	general
Silicon	≤200ºC	sticky, fibers with small microbending losses	industry
HPCF	≤125ºC	hard, possible to remove,eco friendly	industry and medicine
Polyamid	-65ºC-300 ºC	thin, hard, eco friendly	medicine and general

In optical fiber with reduced diameter coating both layers are reduced. Reducing the thickness of the primary coating can lead to lower resistance of the fiber to microbending. And the secondary coating must provide sufficient resistance to external factors. This poses a challenge for current constructors. [7-9]

Microbending losses

Optical pressure sensors detect microbending losses caused by load put on the waveguide. The load causes a set of very small radius bends of the fiber, as shown in Fig. 1. The small radius bends that cause microbending have typically radius <1mm and are described as a random variable with a distribution of spacing and amplitude.

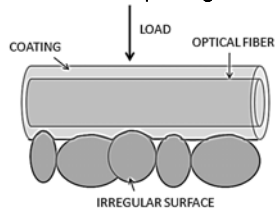

Fig.1. Schematic representation of microbending [10]

The perturbations couple in single mode fiber SMF power of fundamental mode LP_{01} to higher-order modes from where the power dissipates through normal loss and scattering or refraction in to the coating. For most fiber profiles, the spatial periods of the rough surface between 0,2 and 1mm are the most critical for microbending. They can produce a significant deformation of the optical core and cause interaction with the lading modes.

Microbending losses can be controlled as shown in the following equation (1):

(1) $$\gamma = N < h^2 > \frac{a^4}{b^6\Delta^3}\left(\frac{E}{E_f}\right)^{3/2}$$

where: γ - is the macrobending induced attenuation increase, N - is the number of bumps of average height h per unit length, b - is the total fiber diameter, a - is core radius, Δ - is the fiber refractive index difference and E_f and E - are the elastic module of the fiber and the fiber surrounding material respectively [11].

By increasing the coating diameter, the stiffness of the coated fiber also increases. Equation (1) shows that coating diameter has a profound effect on microbending performance.

Lateral Loading Method

This method is commonly used in microbending tests. Fiber samples are placed between two 100 µm sand papers placed on glass plates, as shown in Fig.2. By changing the load in this method, microbending losses of tested fiber are changed.

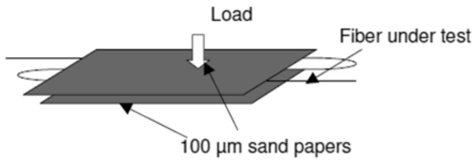

Fig.2. An example of the figure inserted into the text

Tested elements

Three types of SMF were tested: 1) standard SMF described in G.652.D recommendation, called DUT1, 2) bend insensitive SMF with nanostructure ring in cladding described in G.657.B recommendation, called DUT2. Both types have coating about 242µm diameter, which is standard result in telecommunication optical fibers. The third tested optical fiber type was bend insensitive SMF with coating diameter reduced to 200µm described in IEC 60793-2-50 ed4 recommendation, which was called DUT3.Three samples of every type of optical fibers were prepared.

The most important parameters of tested optical fibers are shown in Table 2.

Table 2. The parameters of the optical fibers [12-14]

Name	DUT1	DUT2	DUT3
ITU-T standard	G.652.D	G.657.B	G.657.A1
Fiber name	SFM-28e+	ClearCurve ZBL	-
Cladding diameter [µm]	125.0 ± 0.7	125.0 ± 0.7	125.0 ± 0.7
Coating diameter [µm]	242 ± 5	(242 ± 5)	~200
Mode field diameter [µm]	9.2 ± 0.4 @1310nm 10.4 ± 0.5 @1550nm	8.6 ± 0.4 @1310nm 9.65 ± 0.5 @1550nm	9.2 ± 0.4 @1310nm 10.4 ± 0.5 @1550nm
Cladding non-circularity	≤0.7%	≤0.7%	≤0.7%
Coating-cladding concentricity	<12µm	<12µm	<12µm

Test and results

During the test light source AF-ORL-3.1 and optical power meter Anritsu ML93B with MA913B sensor were used. Moreover, two glass plates 24cm x 28cm with 100µm sand paper placed on them were used. Weight of one glass plate was 0.667kg. Diagram of measuring setup is shown in Fig. 3, and photo of measuring setup is shown in Fig. 4.

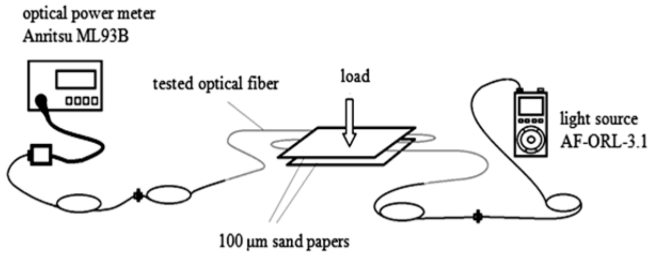

Fig.3. Diagram of measuring setup

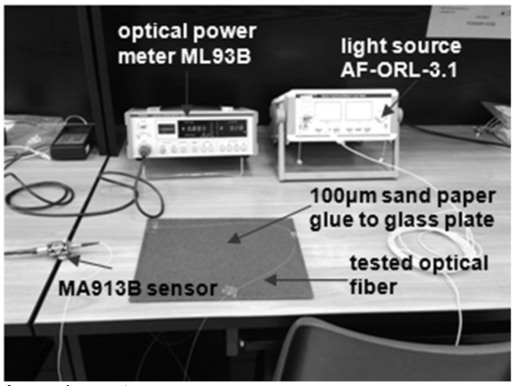

Fig.4. Measuring setup

Three types of placement of optical fibers on glass plate, called A, B, C, were investigated as shown in Fig. 5-Fig. 7.In all three patterns, loaded optical fibers were aligned in straight line and were bent out of glass plates to avoid breaking optical fibers.

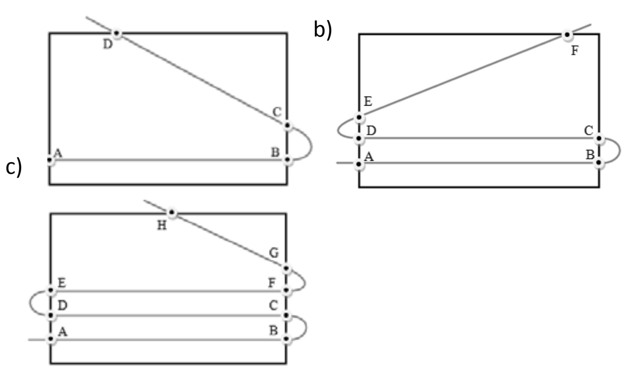

Fig. 5 (a) Pattern A where the length AB+CD is 0.5m, (b) Pattern B where the length AB+CD+EF is 0.8m, (c) Pattern C where the length AB+CD+EF+GH is 1m

Seven different loads were used: 0.667kg, 0.8kg, 1kg, 2kg, 3kg, 4kg, and 5kg. All loads were weighed with ±1g accuracy. Two wavelengths, 1310nm and 1550nm, were used. In Fig. 6 – Fig. 11 the influence of load put on tested optical fibers on their microbending losses is shown. For each sample measurements were conducted five times. Presented results are an average from the data obtained during research.

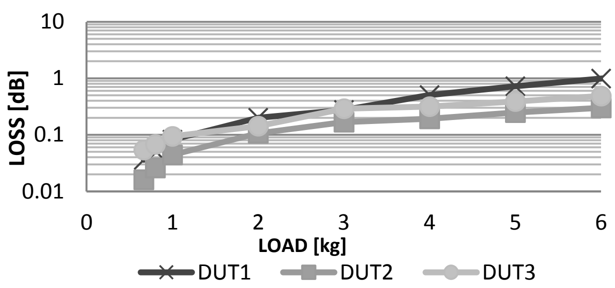

Fig. 6 Loss vs. load for pattern A and 1310nm wavelength

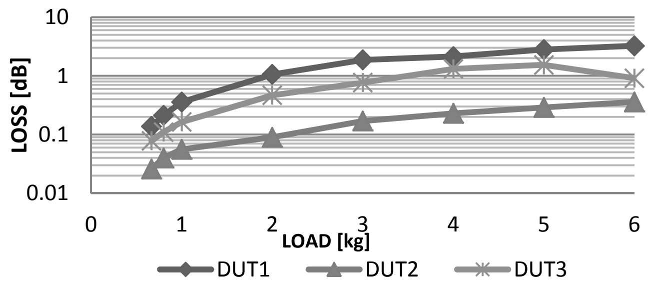

Fig. 7 Loss vs. load for pattern A and 1550nm wavelength

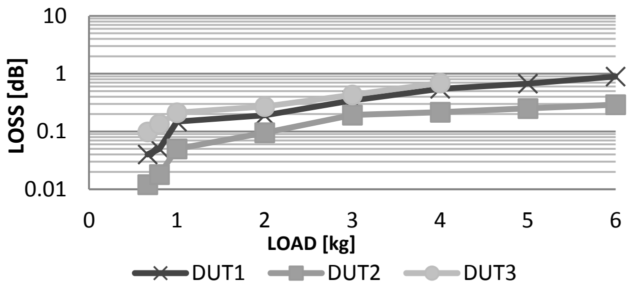

Fig. 8 Loss vs. load for pattern B and 1310nm wavelength

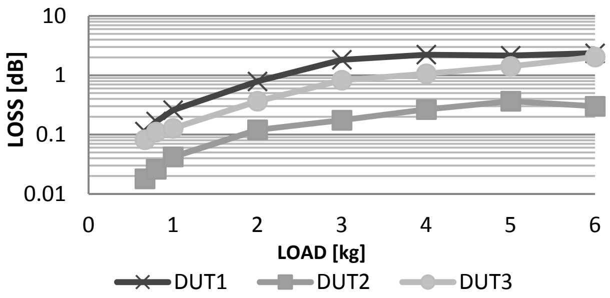

Fig. 9 Loss vs. load for pattern B and 1550nm wavelength

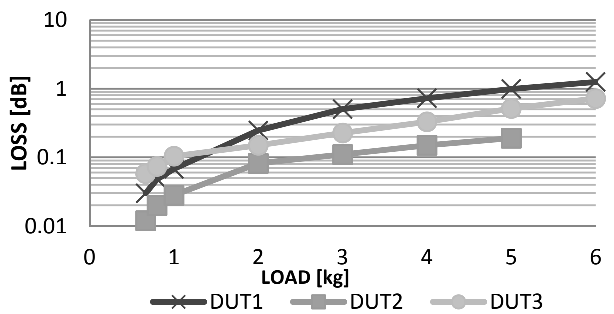

Fig. 10 Loss vs. load for pattern C and 1310nm wavelength

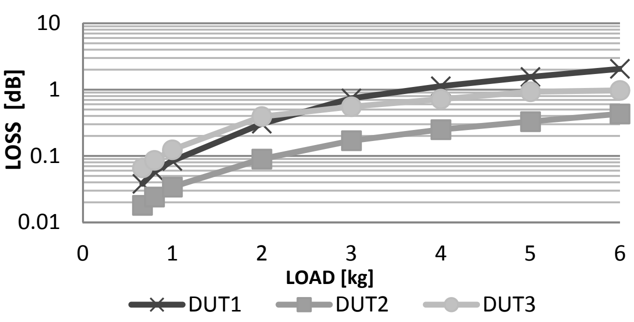

Fig. 11 Loss vs. load for pattern C and 1550nm wavelength

Conclusion

A new type of optical fiber with reduced coating diameter was developed. By reducing the size of optical fibers, their level of insensitivity to microbending should be the same as in optical fibers with thicker coating.Developed optical pressure sensors use the lateral loading method. By analyzing microbending losses, the load can be determined.

While analyzing Fig. 6 - Fig. 11, one can state that although OFRCD has a reduced coating, it has similar mechanical and optical resistance to loadas standard SMF with thicker coating. This information confirms microbending insensitive of OFRCD.However, the most resistant fiber turned out to the fiber with nanostructure ring in cladding - DUT 2. This fiber's special resistance to bending, even in a micro scale, was once again confirmed.

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