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ON THE APPLICATION OF FIBER OPTIC SYSTEM IN GEODETIC WORKS

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Abstract. This paper is an attempt to bring together and summarize the research, based on the use of the new opportunities provided by the development of optoelectronic for engineering geodesy works.
Optical fiber solutions, which are described in this article, have many advantages. One of the most important is the lack of electrical power and indifferent behavior towards strong electromagnetic fields. In addition, this type of solutions are characterized by transmission the measuring signal over long distances, which allows to eliminate the observer from a dangerous work environment. Of course, these methods have some disadvantages. The waveguides are characterized by high fragility and sensitivity of alkaline. Moreover, the prices for fiber-based systems are very high, the reason for this is the high fiber production costs. It should be noted, however, there have been recently observed a significant decline in prices. Taking into account the long-term viability and stability of the sensor there is noticed the upward trend for their use.
This article presents a preliminary division of use of waveguides in the geodetic works. Author describes passive and active ways of using fiber as a part of the measurement system. A significant part of the study is devoted to the description of the active optical fiber sensors. This content refers to the theoretical basis of their operation and the number of measurement points which can be simulated by appropriate selection of the solution. There were specified in comparison types of the measured parameters and precision of their determination for each of the presented sensors. The practical part presented the sensor system in the form of a "delta" rosette and selected effects of the acquisition, processing and visualization of data using dedicated software. At the conclusion, there were classified certain real objects applications and elaborated on the theoretical possibility of using these systems.

Key words: optical fiber, engineering structures, deformations, strain sensors

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INTRODUCTION

The development of the degree of complexity of building structures and increased awareness for maintaining the safety of these engineering structures have led scientists to seek new monitoring systems. The solution to this problem involves an interdisciplinary approach across many fields and a broader use of optoelectronics has been recently observed. One of the main problems involves optical fibers, which owe their dynamic progress to intensified global communication.

Optical fibers are fibers basically built of a core and a jacket. Glass, plastic, liquid and crystalline waveguides can be distinguished with respect to the material type used for core construction [Ziętek 2005]. The essence of optical fiber functioning is a phenomenon called total internal reflection, whose existence is possible at the boundary of two media with different indices of refraction. For this reason, the fiber jacket has a higher index than the core. Light beam propagation takes place mainly in the core, which allows long-distance signal transmission without the need to install amplifiers as additional components. The advantage of optical fibers is their resistance to external factors, both atmospheric and electro-magnetic radiation. Their dimensions and long lifetime allow their application inside and outside structural components. Lack of electrical power supply eliminates any sparking hazard and allows application in explosion-risk areas. There is a natural possibility of long-distance optical signal transmission (reaching several tens of kilometers) and placing the signal analyzer at a spot far from the survey area favorable to the observer.

The scope of using optical fibers in geodetic works is already very broad. The manner of their use can be basically divided into two groups – active and passive. The first group are systems which take part directly in deformation measurements. Passive application of optical fibers should be understood as their indirect use.

PASSIVE OPTICAL FIBER USE

The first passive application is in optical fiber target signalizes, used for the examination of complex structures, where the distribution of the traditional survey point markers is significantly impeded. This signalizer consists of a body, on whose front plane a spotlight is visible which is the optical fiber front face. The light source is usually a laser with instrumentation, necessary for the correct introduction of the light beam determined by the optical fiber numerical aperture. Both the body shape and the distribution of the waveguide beams in the body can vary greatly and be fitted to the characteristics of the examined structure. Tests of direction measurement accuracy suggest the application of these signalizers in angular measurements, where in-creased precision is required. The results determine the average error of the measured direction at 3^{cc} using a total station with a standard error of angle measurement $0{,}3^{cc}$ [Ćmielewski 2002].

A further development of this idea involves targets with a single point optical fiber signalizer. They differ from their predecessors in that they are equipped with targets, a reading system with a nonius and instrumentation for movement in one plane. They can effectively replace the surveying rods used in the fixed reference plane method for survey point signaling. This innovative solution can be applied in geodetic measurements of industrial machinery and equipment, as, for example, lathes [Ćmielewski 2010].

The electronic distance meter tester is another example of passive optical fiber use. In this case, it replaces long comparison bases and al-lows their transfer to the laboratory environment. This eliminates the effect of atmospheric and personal factors to a considerable degree, which substantially translates into the accuracies of the performed tests. An additional strength of these distance imitators is reducing the financial, spatial and material inputs necessary for the construction and maintenance of the known comparison bases [Ćmielewski and Kuchmister (a utility model No. 107750)].

ACTIVE OPTICAL FIBER APPLICATION

Active waveguide use consists in its direct use as a measuring device. It can also be used as a sensor in engineering structure deformation and displacement surveys. Such flexibility depends on the observed optical fiber physical properties and the measured quantity and it is also distinguished by the design of the sensor itself. A division with respect to the number of survey points covered by a single cable can be found in the literature:

- single point optical fibers – the equivalents of electro-optical extensometers and strain gauges;
- quasi-continuous – a single optical fiber is the basis for several observed points;
- continuous – the measurement becomes possible along the entire length [Zasada et al. 2006].

The characteristics of several of the most popular optical fiber sensors used in the market are presented below. Their theoretical application is also described and real structures in whose monitoring they are taking part are detailed.

OPTICAL FIBER SENSORS

FBG sensors have a Bragg grating in the optical fiber core, which functions as a filter. It is characterized by a periodically variable index of refraction and therefore it reflects only the wavelength dedicated for it. The rest of the pulse is transmitted. When stress acts, the sensor, together with the contained grating, deforms and starts to reflect a different wavelength. As a result, the measurement consists in the determination of reflected wavelength change. The sensors of this type measure the sum of mechanical and thermal factors. Therefore, when measuring deformation of the structure, it is necessary to compensate for the effect of temperature on optical fiber strain indications.

The structure of the EFPI sensor consists of two optical fiber sections placed coaxially in one tube. The optical fiber ends are polished to obtain partially permeable mirror surfaces or sprayed with a substance with similar properties. A minimized Fabry-Pérot interferometer is thus obtained. The distance between the mirrors is the total multiple of the wavelength reflected by them. The change caused by deformation results in a jump in the distance between the mirrors and thus in the wavelength returned to the analyzer. The recorded changes in this case are also the sum of thermal and force effects [Skłodowski 2009]. The flaw of these sensors is the limited number of mirrors in one fiber [Zasada et al. 2006].

The principle of operation of the SOFO sensors consists in splitting the light signal into two cables placed in parallel. They are characterized by a slight difference in length. They both have mirrors at one end, while the other ends are connected to a third arm with a coupler. A Michelson interferometer is obtained by the implementation of this design. A thermal deformation changes the length of both optical fibers equally. This shows that these sensors are thermally compensated and only a mechanical factor can cause changes in the length of a tight waveguide. The deformation measurement is the comparison of the difference in the lengths of the optical paths of both rays [Skłodowski 2009].

The DiTeSt and DTSS sensors base their operation on a phenomenon called Brillouin scattering. A high power laser light pulse induces, by a generated ultrasonic wave, crystal structure vibrations in the optical fiber core. The light wave is scattered in the direction opposite to light propagation in the optical fiber. Movable Bragg gratings thus form in the core. A second portion of light is sent by the analyzer. Depending on the reflected wave frequency shift and the maximum frequency value, the deformation value is determined along with the place of its occurrence. This sensor, as with the first two, does not distinguish between mechanical and thermal factors [Zasada et al. 2007]. This device allows measurement in 5-cm intervals and is a continuous sensor [Zasada et al. 2006].

Table 1. Types of sensors, the parameters of the measured and their accuracy [Zasada and Wilde 2007]

sensor type	FBG	EFPI	SOFO	DiTeST DTSS
parameters and accuracy				
deformationμm	1	100	1	
strainμε =1 μm/m	1	1	1	20
pressure [%] full scale		0,25		
temperature [°C]	0,1	0,1		0,2
tiltμrad			30	

Source: (personal elaboration)

APPLICATION

The use of fiber optic sensors is very extensive, as well as number of design of these sensors. Each of them is dedicated depending on the type of test object and the parameters to be measured. One of the example of such structure is the K-OR type rosette by HBM Company.

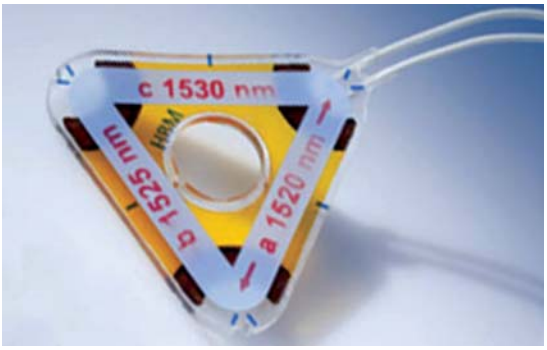

Fig. 1. Rosette K-OR [Maaskant et al. 1997]
Source: (http://www.hbm.com/en/menu/products/transducers-sensors/optical-fiber-sensors/k-or/)

This system consists of three independent FBG sensors which take the "delta" topology. It make possible obtain information about the linear deformation occurring along the arms.

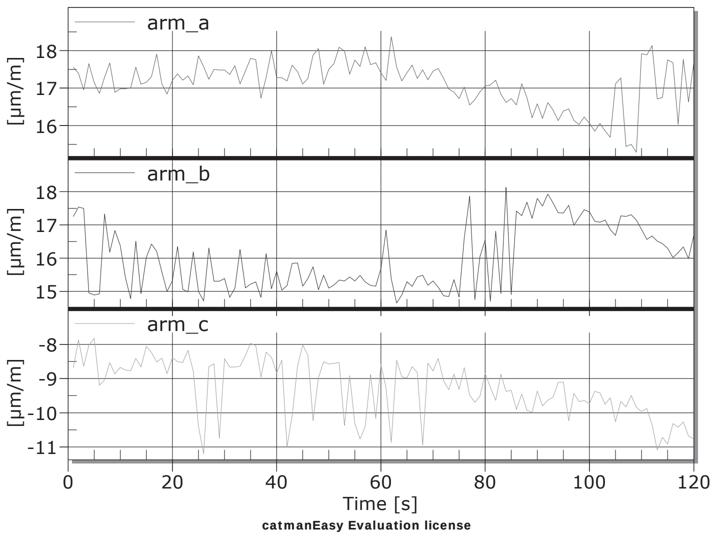

Fig. 2. Strain measurement
Source: (personal elaboration)

Performed measurements can be monitored in real time in the Catman Easy, which is intended to support the HBM products. This data can also be stored in a database, and then they can be processed in computing panel. The results of the work can be presented by variety of graphic imagery. An example of such operation is calculating the linear deflection relative to the Cartesian system.

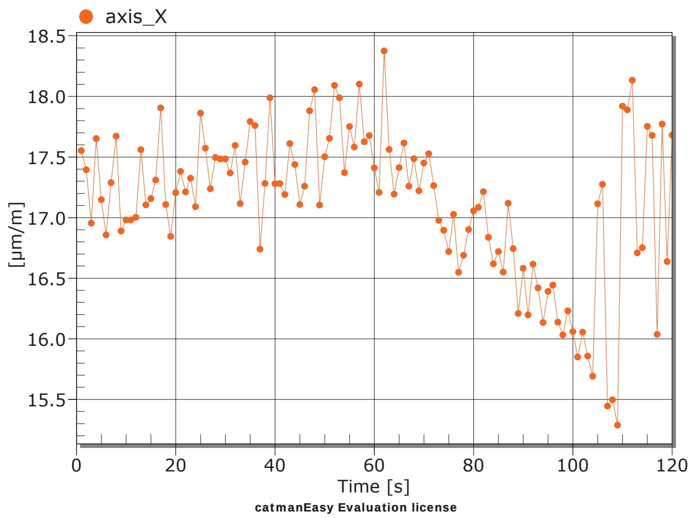

Fig. 3. Strain of the X axis
Source: (personal elaboration)

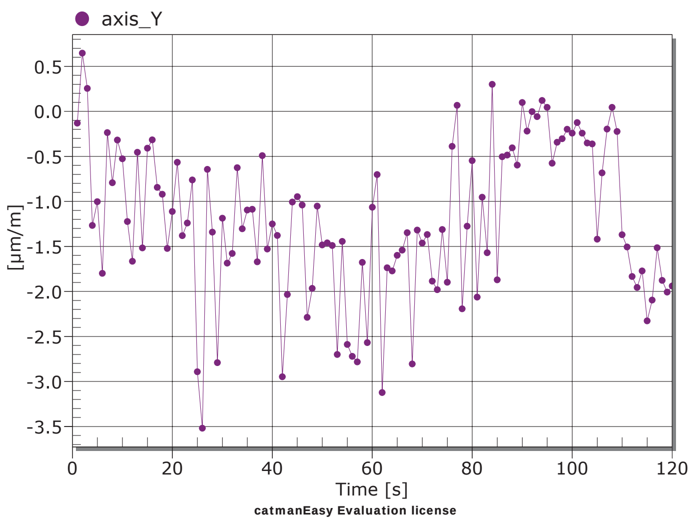

Fig. 4. Strain of the Y axis
Source: (personal elaboration)

Comparing chart 3 and a part of imaging 2. related to "a" arm strain, identity of these two runs can be noticed. This shows the X-axis overlaps with the arm of 1520 nm standard length of reflected wavelength. It should be pointed here that the program accepts the designation of a Cartesian mathematical nomenclature.

There are summarized below in tabular form measurements of the two measurement periods. In both cases, the same mass was affected on controlled object, as well as the place of its application. Catman Easy automatically summarizes main parameters of the conducted measurements. The solution quickly enables control of homogeneous measurement repeatability and condition of a structure at repetitive loads.

Table 2. Comparison of measurements

arm	a		b		c	
unit	[μm/m]					
epoch	I	II	I	II	I	II
samples	121	601	121	601	121	601
min	15.29	15.64	14.64	17.04	-11.20	-11.86
max	18.37	15.64	18.13	21.25	-7.821	-7.562
mean	17.12	15.64	16.01	19.59	-9.251	-9.711
standard deviation	0.6159	0.00084	0.9743	0.9392	0.8334	1.009

Source: (personal elaboration)

The need for new solutions for monitoring affects particularly on dynamic development of this field. However, some of them, requires further experimental work. In the commercial market, FBG sensors are used in the aircraft, shipbuilding and yachting industries. They also find application in the measurement of fissure openings, bridge cable and power line vibrations and truss component deformations. DTSS and DiTeSt sensors are used in large and extensive structures such as dams and levees, roads and bridges, liquid fuel tank fouionsndat, jointless track distortions and identifying cable creep in tensile structures. The literature on the subject reports on the application of the above solutions in the structures [Zasada and Wilde 2007]:

- Third Millennium John Paul II Bridge over the Dead Vistula in Gdańsk;
- bridge over the Vistula in Płock;
- roof of the Olivia Hall in Gdańsk;
- Beddington Trail Bridge in Calgary [Maaskant et al. 1997];
- Taylor Bridge in Canada [Maaskant et al. 1997];
- Luzzone Dam in Switzerland [Skłodowski 2009];
- Versoix Bridge in Switzerland [Skłodowski 2009];
- Gandria Church vault [Skłodowski 2009];
- support piles of the Tainan Science Park in Taiwan [Skłodowski 2009].

CONCLUSION

The possibilities of using optical fibers in geodetic works are very broad. The constant development of this field is producing new prospects which should be fully exploited. The installation of these systems in new-ly built structures does not pose problems. However, the question has to be asked of how to use these solutions in already existing structures, in which control measurements by traditional methods have been performed for many years. The results of these works cannot be disregarded and forecasting cannot be based only on the results of new systems. Further research is therefore necessary, not only on pioneering de-sign solutions, but also on methods of introducing measurement results into the existing data resources.

The current works are intended to join FBG sensors and SOFO in one monitoring system. The next step will be installing the system in one of the sample structure of handling and collecting measurement data. Then results will be compared with the data acquired from the geodetic control measurements crane.

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WYKORZYSTANIE SYSTEMÓW ŚWIATŁOWODOWYCH W PRACACH GEODEZYJNYCH

Streszczenie. Praca ta jest próbą zestawienia i podsumowania badań naukowych, opartych na wykorzystaniu nowych możliwości zapewnionych przez rozwój optoelektroniki dla prac geodezji inżynieryjnej. Rozwiązania światłowodowe, które są opisywane w tym artykule, mają bardzo wiele zalet. Głównymi z nich są brak zasilania elektrycznego oraz obojętne zachowanie wobec silnego pola elektromagnetycznego. Dodatkowo rozwiązania tego typu cechują się przesyłaniem sygnału pomiarowego na duże odległości, co umożliwia eliminację obserwatora z niebezpiecznego dla niego środowiska pracy. Oczywiście metody te nie są pozbawione wad. Falowody cechują duża kruchość oraz newralgiczność na odczyn zasadowy. Ponadto ceny systemów opartych na światłowodach są bardzo wysokie. Przyczyną tego jest duży koszt wytworzenia samego przewodu. Należy jednak nadmienić, że w ostatnim czasie obserwuje się dość znaczny spadek cen. Uwzględniając przy tym długotrwałą żywotność i stabilność czujników, zauważalny jest wzrostowy trend ich wykorzystania.
W artykule tym dokonano wstępnego podziału wykorzystania falowodów w pracach geodezyjnych. Autor opisuje bierny i czynny sposoby użytkowania światłowodów jako element systemu pomiarowego. Znaczna część opracowania przeznaczona została na opis aktywnych czujników światłowodowych. Treść ta dotyczy podstaw teoretycznych ich działania oraz liczby punktów pomiarowych, które mogą być symulowane przy odpowiednim doborze rozwiązania. Wyszczególniono w zestawieniu rodzaje mierzonych parametrów oraz precyzję ich wyznaczania dla każdego z prezentowanych sensorów. W części praktycznej przedstawiono układ czujników w kształcie rozety typu „delta" oraz wybrane efekty pozyskiwania, przetwarzania i wizualizacji danych przy wykorzystaniu oprogramowania dedykowanego. Na zakończenie wypunktowano niektóre zastosowania na obiektach rzeczywistych oraz podjęto rozważania o teoretycznych możliwościach wykorzystania tych systemów.

Słowa kluczowe: światłowód, obiekty inżynierskie, deformacje, czujniki odkształceń

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