

REWIEV OF OPTICAL FIBER TECHNOLOGY MEASUERMENT SYSTEMS AND APPLICATION

Moldovan Octavian Alin [1], Țarcă Radu Cătălin, Moldovan Ovidiu Gheorghe[3] and Ghincu Remus Vladimir[4]
[1] University of Oradea, Moldovan.o.alin@gmail.com
[2] University of Oradea, rctarca@uoradea.ro
[3] University of Oradea, omoldovan@uoreadea.ro
[4]University of Oradea,, remusghincu@yahoo.com

ABSTRACT: This paper aims to review Fiber Bragg Grating sensor technology and state of the art, focusing for the application of the technology for temperature measurement in electric motors, to evaluate the thermal phenomena in electric motors for industrial porpoises.
KEYWORDS: optical sensors, FBG, interrogators, gratings

1. FIBER BRAGG GRATING (FBG) SENSORS

The main industry that has driven the development of optical fiber technology has been mainly the field of telecommunication technology.

The photosensitivity characteristic of this type of optical devices allows the manufacturing of phase structures widen the core of the optical fibers called Bragg grating[1]. The fibers Bragg grating are able to realize a large number of functions, (reflection and filtering), with good characteristics, reliability and stability in various environments. [1]

Fiber Bragg gratings are made using two main techniques, namely holographic technique and noninterferometric, techniques based on exposure to UV radiation periodically along a fiber [2].

For the manufacturing of Bragg grating the transverse holography technique is most commonly used [3]. The main advantage of the this method consists in the possibility to modify angle between the beams in such a manner as to generate different periods, and thus make FBG with different wavelengths [4].

FBGs sensors produce signals that are wavelength encoded and have a major advantage over their electronic contra parts namely that this signals are immune to the naturally occurring phenomena of instrumental drift (characteristic of electronic sensors) and also are not affected by the environment influence [5].

The basic sensing principle of a FBG is the modification of the Bragg wavelength (Bλ). The shift of the wavelength is caused by the change the monitored parameter (either strain or temperature, according to the equation (2)[5]

In fig.1 the FBG sensor structure is presented.

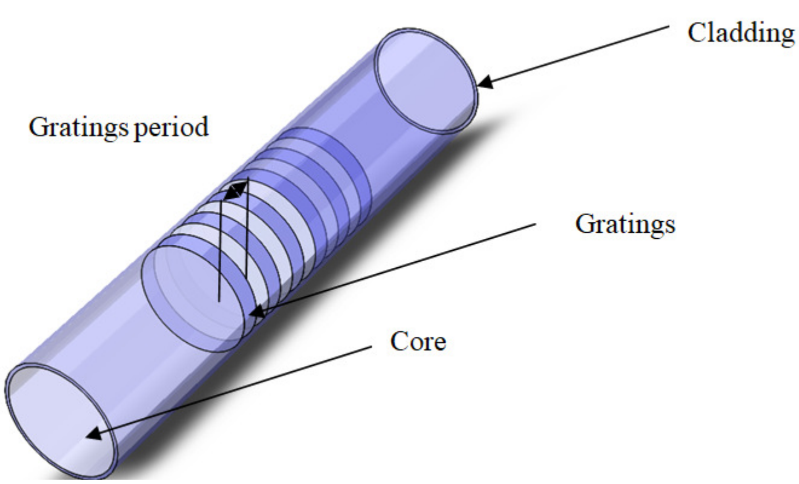

Figure 1. Internal structure of a FBG sensor

The gratings are distributed along the fiber in series [6]. This grating acts as a reflective element for a specific wavelength which is reflected [7] according to the equation (1).

$$\lambda_{Bragg} = 2n_{eff}\Lambda \quad (1)$$

Where:

λ_{Bragg} is specific wavelength that is reflected, also called Bragg wavelength,

n_{eff} is a characteristic of the material called effective refractive index

Λ is the gratings period.

$$\frac{\Delta\lambda B}{\lambda B} = (1 - P_e)\varepsilon + [(1 - P_e)\alpha + \xi]\Delta T \quad (2)[5]$$

where Pe is the photo elastic constant of the fiber, ε is the strain induced on the fiber, α is the fiber thermal expansion coefficient and ζ is the fiber thermal-optic coefficient[5].

One of the main advantages of this FBG sensor technology is the constructive propriety of these sensors to be connected in series [8]. In practice, a large number of fiber Bragg gratings sensors can be realized on a single optical fiber, or several sensor can me connected together, the only requirement being a difference in the base wavelength of each sensor[8]

1.1 Fiber Bragg Grating (FBG) strain dependence

By differentiating the wavelength, the relation between the strain and fiber Bragg grating can be determined [8]

$$\frac{\Delta\lambda}{\lambda_0} = \frac{\Delta(n_{ef}\Lambda)}{n_{ef}\Lambda} = \left(1 + \frac{1}{n_{ef}}\frac{\partial n_{ef}}{\partial \varepsilon}\right)\Delta\varepsilon =$$

$$(1 + P_e)\Delta\varepsilon \leftrightarrow \frac{\Delta\lambda}{\lambda_0} \quad (3)[8]$$

Where

k – is the k factor of the Bragg grating,

Pe – is equal to. 0.21 and is called photo elastic constant

In this case the sensitivity of a FBG strain sensors is given by the equation

$$\frac{\Delta\lambda}{\lambda_0} = k\lambda_0 = 0.79\lambda_0 \quad (4)[8]$$

For a 1554 nm FBG the strain sensitivity is:

$$\frac{\Delta\lambda}{\lambda_0} = 1.22766pm/(\mu m/m) \quad (5)[8]$$

1.2 Fiber Bragg Grating (FBG) temperature dependence

$$\frac{\Delta\lambda}{\lambda_0} = \frac{\Delta(n_{ef}\Lambda)}{n_{ef}\Lambda} = \left(\frac{1}{\Lambda}\frac{\Lambda}{\partial T} + \frac{1}{n_{ef}}\frac{\partial n_{ef}}{\partial T}\right)\Delta T =$$

$$(\alpha + \xi)\Delta T \quad (6)[8]$$

Where:

α – is the thermal expansion coefficient

ζ– id the thermo-optic coefficient (the influence of the index of refraction on temperature)

For the pproximation of the temperature sensitivity we set these values as constant for the entire temperature domain[8]:

$\alpha = 0.55 \times 10^{-6}/°C$

$\zeta = 5.77 \times 10^{-6}/°C$

Having the above assumptions, the approximate value for the thermal sensitivity is presented in equitation 7

$$\frac{\Delta\lambda}{\Delta T} = (\alpha + \xi)\lambda_0 = 6.3\lambda_0 \quad (7)\ [8]$$

For a 1554 nm FBG its thermal sensitivity is:

$$\frac{\Delta\lambda}{\Delta T} = 9.7902pm/°C \quad (8)[8]$$

2. FBG INTERROGATORS

FBG sensors require interrogation systems in order to extract the information from the wavelength shift information[9]. The interrogation techniques permit the extraction of the relevant information, encoded in the reflected signal of the FBG sensors.

The most simple design if interrogator that can be used to detect the variations in reflected wavelength is presented in fig. 2. A wide-band light source is connected to emit light trough the FBG. Then, the reflected beam is passed to a optical spectrum analyzer (OSA)[10]

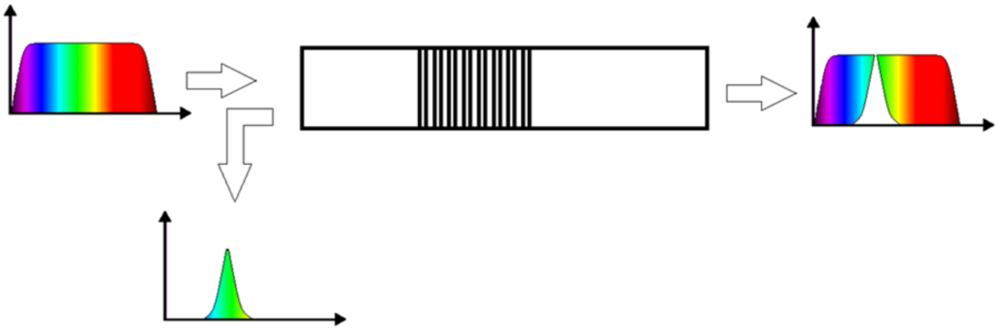

Figure 2. Principle of FBG measuring

In order to be able to determine the wavelength shift wide range methods for methods have been proposed which can be classified as follows[11],[9].

- Tunable-filter-based interrogation
  - AOTF-based interrogation
  - F-P-filter-based interrogation
- Interference interrogation methods
  - Nonequilibrium M-Z interferometer method
  - Michelson interferometer method
- Tunable-light-source-based interrogation
- Interrogation using tilted fiber gratings
- Wavelength-to-time mapping interrogation

3. APPLICATION OF FBG SENSORS

There are two principal ways of using FBS sensors, first being as a temperature sensor and the second is as a strain sensor. Regardless of the usage the principle is the same, only the cause of the wavelength refraction change differs.

3.1 Summary of applications of FBG sensor applications

Table 1. Applications of FBG sensors

Sector	Applications	Reference
Energy	Wind turbines	[12], [13], [14], [15], [16]
	Power grids	[7],[6],[17], [18]
	Geothermal	[19], [20],[21]–[23]
	Solar power	[24],[25]
Civil and industrial constructions	Buildings structural monitoring	[26],[27],[4],[28], [29],[30],[31],[32],[33]
	Smart building applications	[34],[35]
	Pipelines and underground structures	[36],[37],[38],[39],[40]
Biomedical	Hart rate and respiratory function	[41],[42],[43], [44],[45]
Industrial Engineering	Machine tool parameters	[46]–[52]
Electrical Engineering		[53],[54],[53], [55]–[62]

3.2 Use of FBG sensors in multi parametric monitoring systems.

In the paper [26] is presented the development of a FBG based sensing system for structural health monitoring system. The system was applied in China for monitoring ancient buildings. The system developed in paper [26] include four components: Sensor subsystem, the automatic subsystem for collecting and transmission of information, the system for management and storage of acquired information.., an early warning sistem, and a system for the structural evaluation [26]. The system is design to acquire data related to beam deflection angle inclination of the columns of the building, temperature and humidity.

Another multi parametric measurement system using FBG sensors in presented in paper [63] where a refractive index, temperature and curvature based on the splicing-point tapered FBG-SMF-FCF-SMF (FBG, fiber Bragg grating; SMF, single-mode fiber; FCF, four-core fiber) Mach-Zehnder interferometer (MZI) is proposed.

FBG sensors are used in smart home application as presented in paper [64]. The FBG sensors are used to determine the occupancy in the Smart Home.

3.3 Use of FBG sensors for temperature monitoring.

One of the main uses of FBG sensors is the measurements of temperature. In the case of these sensors, the measurement, the Bragg wavelength is a function of thermal expansion of the fibber material and also the change of the reflexive index of the material. There are several advantages of using FBS based temperature sensors. First is the fact that there is no electro-magnetic interference due to the work principle of the sensors.

The earliest paper presenting such a sensor is presented by Morey W.W[65]. The wavelength of the sensor was 830 nm and it had temperature sensitivity of 6.8 pm/ °C. By 1994 the sensitivity rate has reached 10 pm/ °C as presented in the paper [66]The sensor presented in paper [10] had a wavelength of 1300 nm.

In paper [67] novel method of improving the temperature sensitivity is presented. According to [11] the temperature sensitivity of the bare FBG was 0.010 nm/°C and the one coated was at least 0.026 nm/°C.

One of the main fields of applications temperature sensors based on FBG is the electrical systems (large power systems, or other systems with a heavy electromagnetic component) due to their inherent immunity to electromagnetic interference.

In the paper [7] a novel technology for continuously measuring the temperature of overhead high voltage transmission lines is presented. The paper presents the advantages of this type on sensors regarding the stability and resilience to electromagnetic fields.

3.4 Use of FBG optical sensors for strain monitoring

FBG sensors are considered as an high-accuracy monitoring sensor and widely used in structural health monitoring (SHM) [28] . The possibility to attached to a wide variety of substrates and also there dimension which allows to be put in very small places, makes them available for many applications[27].

The reflected wavelength of the FBG sensors is determined with the optical interrogator. The relation between the strain and wavelength variation respectively the wavelength is given by the formula.

$$\Delta\lambda/\lambda = k\cdot\varepsilon \qquad (2)[68]$$

λ base wavelength of the fiber Bragg grating
$\Delta\lambda$ wavelength variation
ε strain
k gauge factor k

FBG sensors have several advantages and are use in industries with a high degree of complexity. In papers [14].

The paper [14] presents a FBG sensors epoxy laminated under tension loading, and the application of real time monitoring using the FBG strain sensors. The ongoing monitoring of possible damages during operation will become an important issue in aircraft safety[14]. According to [14] the application of FBG strain sensors as embedded sensors in composite material structures applied in aerospace industry can solve some of the challenges faced by the use of this materials, trough it's ability for early prediction of fatigue or other type of damages before these reaches a critical stage [14].

The paper concludes that the proposes embedded FBG sensors are able to determine initial damage and the following growth of the damage properly[14].

The paper [69] presents a proposal for a microwave-photonic sensor system (MWPSS) for real-time determination tire strain in automotive. The proposed system is based on two 2π-FBGs with equal bandwidths, the same central Bragg wavelength, but unique address frequency spacing, thus realizing the microwave-photonic measurement methods and providing their address [69]. The data acquired from this novel system is processed in order to determine the tire-road contact characteristics and also for the control of vehicle dynamics [69].

The main use of strain FBG sensors is measurement is in the construction industry. In the paper [70] a novel method of soil strain measurement is presented. The system is based on fiber Bragg grating (FBG) sensing technology. The designed system uses simple design having the advantage of a high life expectancy and high fatigue tolerance, being an ideal candidate for in-situ implementation [70].

Another application of FBG in the field of construction is presented in the paper [71] where an novel method for monitoring the pipeline is presented. Pipeline monitoring is important for preventive maintenance and also for the safety of pipeline transport system. Another factor that has to be taken into consideration is the environmental aspect of pipeline safety, especially for those system transporting dangerous pollutants or even toxic fluids, case in which the early prediction of problems is of most importance. [71].

3.5 Use of FBG in electric drives

The main advantage of FBG sensor is related to the fact that they are not sensitive to electromagnetic influences. This is due to their working principle based on light reflection.

In the paper [6] a system for monitoring icing on overhead transmission lines is presented. The system uses fiber Bragg grating (FBG) strain sensors. The result presented in the paper demonstrates the capacity of the developed system to detect ice in the range of 0-30mm with a sufficient accuracy.

Also several studies are using the FBG sensors in monitoring the parameters (either electrical or of other nature) of electric motors. In the paper [72] reports a study of fiber Bragg Grating (FBG) sensing application that is able to simultaneous extract the thermal and mechanical parameters on the operation of an electric machine. According to the research realized in [72] the data obtained using FBG sensors contains information regarding the mechanical and thermal phenomena in the electric motor and moreover the information can be distinguished.

Other studies focus on fault detection in electric motors using FBG sensors. In paper [53] such a study is presented a technique for detection of stator short circuits, taking advantage of the FBG sensors propriety to be immune to electric fields. The paper focuses on the thermal characteristic of the inter-turn fault and such uses the FBG sensors as temperature sensors

4. CONCLUSION

FBG technology has a relative short history in sensory application. Never the les the vast advantages this type of sensors has made them wide spared in numerous fields of activity. Their robust construction made them suitable for application in harsh condition industries such as energy, oil, gas and pipeline monitoring.

Also their characteristics in sensitivity and accuracy make them suitable in critical application such as health care industry.

The propriety of these sensors to not be influenced by electric and magnetic fields is a unique feature and an ideal candidate for applications in power electronic (power transformers, electric machines etc)

5. ACKNOWLEDGEMENTS

"This paper was funded through the project" SmartDoct -High quality programs for doctoral students and postdoctoral researchers of the University of Oradea to increase the relevance of research and innovation in the context of regional economy ", ID / Project code: 123008, co-financed from the European Social Fund through the Human Capital Operational Program 2014-2020 "

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