ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering
(IJERCSE)
Vol 5, Issue 1, January 2018

Review on Optical Fiber Sensor

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Abstract: The current status of fiber-optic sensors is reviewed. The optical fiber sensors have certain advantages, including immunity to electromagnetic interference, lightweight, small size, high sensitivity, large bandwidth and ease of implementation of multiplexed or distributed sensors. The most widely studied measurements are strain, temperature and pressure and the fiber grating sensor represents the most widely studied technology for optical fiber sensors. Fiber optic gyroscopes and fiber optic current sensors are good examples of a rather mature and commercialized technology for optical fiber sensors. In this paper, in particular, technologies such as fiber grating sensors, fiber optic gyroscopes, and fiber optic current sensors are discussed with emphasis on the principles and current status. Today, the marketing of optical fiber sensors has found some success. They are still suffering from competition with other mature sensor technologies in various fields. Nevertheless, new ideas are being developed and tested on a continuous basis not only for conventional measurements but also for new applications.

Keywords: Fiber grating, Fiber-optic gyroscope, Optical fiber current sensor, Optical fiber sensor.

INTRODUCTION

Progress in fiber-optic communication[1] lines has stimulated rapid growth of sensors and transducer transducers of physical effects using signals of the same nature as those used in communication lines (i.e., optical radiation). Industry demands for optical sensors that can operate under conditions when there is a risk of explosion or when exposed to high-energy radiation, strong electromagnetic fields or high temperatures.

In general, in addition to fiber-optic communicationlines, optical fibers can be used in the following (Figure 1):

1) Fiber-optic sensors utilizing a waveguide as a sensitive medium;

2) Optical sensors[2] not made of fiber waveguides (when the latter are employed only to deliver and carry away optical energy);

3) Non-optical sensors requiring the presence of an additional output signal-optical radiation converter which may be considered as an essential part of a sensor in the case of fiber-optic communication lines.

What's more interesting is the use of the first two sensor styles. The fiber optic sensors as well as the point-like sensors can be distributed. For distributed sensors the radiation interacts with the physically measured quantity in a certain section of a sensitive waveguide, and the output signal is proportional to the length of the interaction. Point-like sensors at discrete locations can detect outer disturbances.

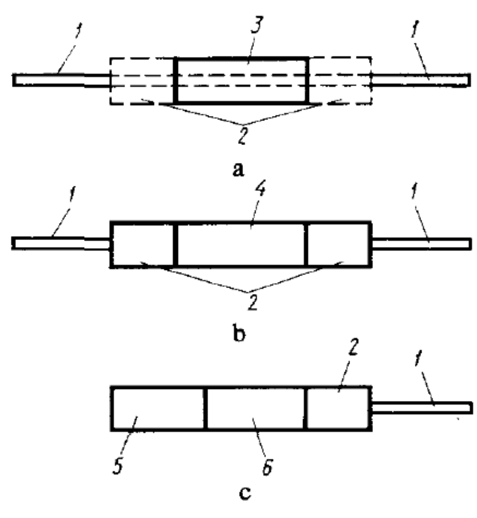

Figure1: Fiber-Optic (a), Optical (b), and Non-optical (c) Sensors for Fiber-optic Communication Lines: 1) Fiber Waveguide; 2) Optical Couplers; 3) Fiber-Optic Sensor; 4) Optical Sensor; 5) Non-Optical Sensor; 6) Optical Converter.

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ISSN (Online) 2394-2320

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Figure 2 shows the general structure of converters in an optical (or fiber-optic) sensor. The measured quantity can be an electrical or magnetic field intensity, an electrical current J, temperature T, Linear velocity, angular and linear velocity, force F, pressure p, and so on. The external perturbation may be of electrical, magnetic, thermal, mechanical, chemical, radiation or other types, depending on the nature of the measured quantity.

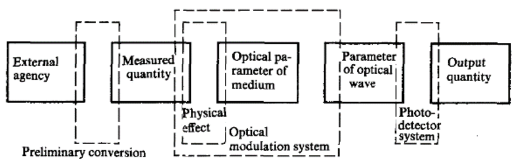

Figure 2: Schematic Representation of the Processes of Conversion of Physical Quantities in an Optical Sensor

Hence, a preliminary conversion method (which is necessary if we cannot directly measure an external disturbance, such as linear acceleration, Or where a sensor is available capable of measuring a different physical quantity) it can be electromechanical, magneto-mechanical, electronic, electromagnetic[3], etc. The measured quantity (E, H, J, T, F,p, etc.) alters the optical parameters (refractive index n, absorption coefficient of light x, linear dimensions) of the medium in which light is traveling and this happens because of a physical effect (electro-optic or magneto-optic, piezoelectric, acousto-optic or piezo-optic, etc.).

The following section discusses fiber grating sensor[4] technology, which is the most popular topic in fiber optic sensors. Two very advanced topics fiber-optic gyroscopes (FOGs)[5] and fiber-optic current sensors are studied afterwards. Other sensors are briefly discussed in the last segment, which is accompanied by some closing remarks.

Fiber Grating Sensors:

Although the formation of fiber gratings was reported in 1978, intensive study on fiber gratings began after a controllable and effective method was devised in 1989 for their manufacture for optical communications, fiber gratings were applied to add/drop filters, amplifier gain flattening filters, dispersion compensators, and fiber lasers etc. Extensive studies were also carried out on fiber grating devices, and some of them have now entered marketing levels.

Figure 3 shows fiber gratings types. A fiber Bragg grating (FBG) couples the forward propagating core mode to the backward propagating core mode under phase-matching conditions. A long-term fiber grating (LPG)[6] may combine forward propagating core mode with one or several forward propagating cladding modes. A chirped fiber grating has a broader spectrum of reflection and each wavelength component is reflected in different positions;

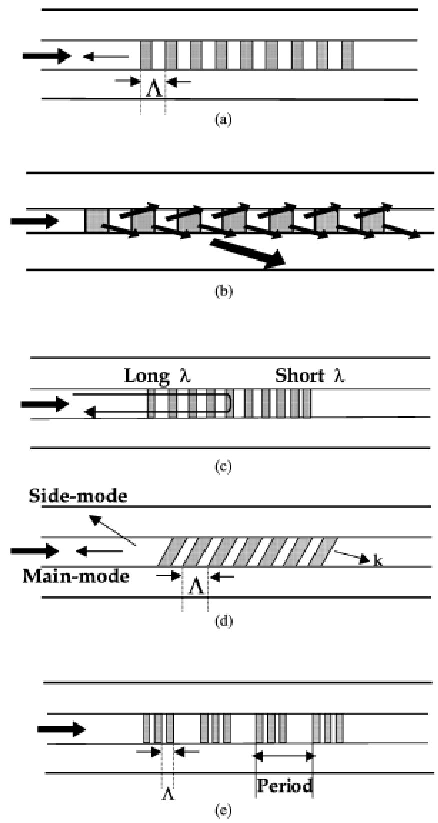

Figure3: Types of Fiber Gratings. (a)Fiber Bragg Grating, (b) Long-Period Fiber Grating, (c) Chirped Fiber Grating, (d) Tilted Fiber Grating, (e) Sampled Fiber Grating.

It results in a disparity in delay time for different wavelengths reflected. The forward propagating core mode can be combined with a tilted fiber grating to the backward propagating core mode and a backward propagating mode. A sampled fiber grating may reflect several components of wavelength with a spacing of the same wavelength. All these types of gratings were used in various types of fiber grating sensors and interrogators for the change of wavelength. Among them, however, FBGs are the most widely used as sensor heads.

In FBGs the Bragg wavelength λ_B, or the wavelength of the light that is reflected, isgiven by

$$\lambda_B = 2n_{eff}\Lambda,$$

Where n_{eff} is the effective refractive index[7] of the fiber core and Λ is the grating period.it can be seen that the Bragg wavelength is changed with a change in the grating period or the effective refractive index.

Fiber-Optic Gyroscopes:

It is generally acknowledged that the FOG's first demonstration was achieved 27 years ago, although a few previous studies had been done. The basic concept is based on the interferometer from Sagnac, and is quite simple. It is a good example of how special relativity is applied. Two lights traveling in opposite directions in the spiral experience different lengths for a rotating optical fiber coil, as shown in Figure 4, resulting in different travel times and a phase difference in the two optical waves. Simple analyses show that the phase difference φ is given by

$$\Delta\varphi = \frac{8\pi N}{\lambda c} A.\Omega$$

Where N is the number of coil turns, λ the wavelength in vacuum, c the speed of light in vacuum, **A** the area vector of the fiber coil (Its magnitude is the area enclosed by the single turn coil and direction is normal to It.), and **Ω**the rotating rate (angular frequency) vector.

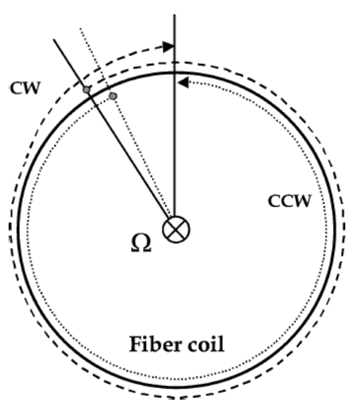

Figure4: Principle of the Fiber-Optic Gyroscope

Fiber-Optic Current Sensors:

With the capacity growth of electric power systems, the role of protection relay systems is becoming increasingly important. Such a system can recognize any sudden failures immediately, such as a surge, and separate the fault parts from the power systems. The role of safety relay systems is becoming increasingly important with the capacity growth of electrical power systems. Such a system can immediately recognize any sudden faults, such as a surge, and isolate portions of the power systems from the fault. Moreover, with the super-increase in voltages (several hundred kV) in power distribution systems, it becomes more difficult and costly to insulate the CTs. Optical current sensors that do not suffer from electromagnetic interference are therefore good replacements for conventional CTs.

The deregulation and development of independent power producers and regional transmission companies have created a need for several new high-voltage revenue metering points, in addition to safety relays. A 0.5 % uncertainty in metering can result in an uncertainty of millions of dollars per year at a high-power metering location when transferring power from a generation company to a regional transmission company. Hence the future use of high precision optical CTs is exciting.

Linearly polarized optical waves are input into the optical fiber coil in optical fiber CTs. The linear polarization can be mathematically expressed as a superposition[8] of two circular polarizations (right and left). A circular birefringence within the optical fiber coil is induced by the magnetic field induced around a current carrying element. Therefore a relative phase difference between two circular polarization components is generated after passing through the coil, this results in the linear polarization angle rotation in proportion to the supplied current and the number of fiber turns.

Even though the concept is quite simple, several difficulties are encountered in actual implementations which limit the resolution of the sensor systems. Given the imperfection of the core shape, optical fibers have some linear birefringence, which may distort optical fiber CT outputs. By annealing this linear birefringence[9] can be considerably reduced. But, in practice it has a difficulty because the annealing is usually done after the fiber coil winding cycle. There is an unavoidable linear birefringence which is caused by bending optical fiber around the current-carrying part. In addition, the effects of vibration, mechanical stress or variation in strain and temperature on the linear birefringence are also critical. High-current, carrying conductors vibrate in some applications. The vibration to rotate the fiber coil in such a direction is more critical, because in that case the fiber coil acts as a FOG.

Several techniques were proposed for dealing with these problems. If a birefringence bias corresponding to a phase difference of 258 degrees is applied, the effect of the linear variation in birefringence can be minimized. However a factor of 0.217 reduces the sensitivity. Tokyo Electric Power Company has developed current sensors with flint glass fibers with a low photoelastic coefficient (4.5×10^{-10} cm2/kg) and a high Verdet constant (0.065 min / Oe cm), But they suffer higher losses, trouble splicing with other fibers and higher costs. A recent report indicates that a differential current relaying system was successful in hammering and thermal shock tests.

Often suggested was the use of twisted optical fiber, in which a high circular birefringence is produced and thus the effect of linear birefringence minimized. For this use, a high birefringent spun fiber was also proposed which is pulled during the fiber drawing process from a rotating silica preform. These kinds of methods of increasing circular birefringence are in use in most of the today's optical fiber CTs.

Others:

Some other types of optical fiber sensors were marketed based on very simple concepts. Examples include the displacement or pressure sensor based on two-fiber light coupling, A liquid level sensor based on irritated complete internal reflection, a pressure sensor using a wiggled (periodically bent) thread, and a temperature sensor based on radiation detection from a heated sensor head (black body cavity).

OTDR, which is focused on tracking backscattering along the cable, is one of the most well-developed and commercialized in-line fiber sensors or diagnostic instruments. The idea is also quite old and the OTDR[10] has become a standard technique for checking the connections between optical fiber. It typically provides spatial resolution of the sub-meter but improved techniques can provide resolution of the mm-order. To achieve mm or sub-millimeter (~10 μm) spatial resolution, more complicated methods such as optical frequency domain reflectometry have been studied.

For marine or submarine applications optical fiber acoustic sensors or optical fiber hydrophone systems were also intensively studied and tested. Low coherence fiber-optic interferometry was also marketed for civil applications. Chemical fiber-optic sensors or biosensors were continually examined. The principles are based on the monitoring of absorption, reflectance, luminescence, reflective index change or light dispersion and are aimed at oxygen, pH, Demand for carbon dioxide, ammonia, detergents, biochemical oxygen, pesticides, and moisture. In many cases, optical fibers are simply used to guide light in the specimen to the measuring point. In some cases, optical fibers monitor a material deposited at the end of the fiber for the response. In some other cases well-developed sensor technologies have been used for biological research, such as FBG temperature sensors.

CONCLUSION

The current status of optical fiber sensors was briefly discussed in this paper. After the production of optical fibers it was believed that they could also be used for sensors. The history of optical fiber sensor research is therefore almost as old as the history of research on optical fiber communication. Optical fiber sensors have unique benefits such as high sensitivity, EMI immunity, small size, lightweight, robustness, and the ability to deliver multiplexed or distributed sensing. Although the optical fiber sensors did not experience the spectacular commercial success of optical fiber communications, they were researched constantly and with enthusiasm.

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