International Journal of Engineering Research and General Science Volume 3, Issue 5, September-October, 2015
ISSN 2091-2730

Fiber Optic Sensor technology for Non-optical parameter measurement

Swapnil R. Chilap [1], Mrs. Kadambari Sharma [2],
[1]M.E.Student, [2]Assistant Professor, Department of Instrumentation Engineering,
Vivekanand Education Society's Institute of Technology,
Mumbai, swapnil.chilap@ves.ac.in, 09821757816.

Abstract— Use of traditional electronic sensors is limited in harsh, electromagnetic and high radio frequency environments which started interest in fiber optical sensing. Fiber optic sensors were developed by combining optoelectronic devices with fiber optic telecommunications systems. Optimization of components, cost reductions and recent researches gives fiber optic sensors with improvement in size, quality and performance. Commonly used fiber optic sensors are Intensity based, phase modulated and wavelength modulated fiber optic sensors. In this paper, an overview of fiber optic sensors, their working principle and non-optical parameter measurement applications are presented.

Keywords— Optical fibers, fiber optic sensors, optical sensing, Extrinsic sensors, Intrinsic sensors, interferometers, light field

INTRODUCTION

In recent years the field of measurement and instrumentation with particular sensor development is rapidly expanding. Growth of optoelectronic and the fiber optic telecommunication industries leads to the development of fiber optic sensors. In fiber optic sensor optical fiber is used in two ways, either it is used to communicate with a sensor device or use fiber as the sensor itself. Now fiber optics is opted in many fields which results into the constant development and mass production of optical fibers and fiber optic sensors. Fiber optic sensors are replacing traditional sensors because of their compact size, better performance and cost reductions.

Fiber optic sensors are capable of measuring a wide range of environmental parameters. The advantages of fiber optic sensors over conventional electronic sensors are as follows:

- Easy implementation.
- Bad conductors of electric current.
- Ability to withstand electromagnetic interference and radio frequency interference.
- Lightweight, Robust, more resistant to harsh environments.
- High sensitivity, Multiplexing capability to form sensing networks.
- Distributed and quasi distributed sensing capability.
- Capability to sense a wide range of environmental parameters [2-8].

Fiber optic sensor:

The general structure of an optical fiber sensor system consists of light source, optical fiber, sensing element i.e. transducer, an optical detector and signal processing electronics (oscilloscope, optical spectrum analyzer etc). Optical signal generated by the light source is passed to the transducer through optical fiber. Environmental parameters sensed by the transducer modulates the optical signal. Modulation can be in the form of intensity, phase, wavelength or polarization state which is detected by an optical detector and passed to the processing electronics for further interpretation. Light source can be LED, LASER or laser diodes etc.

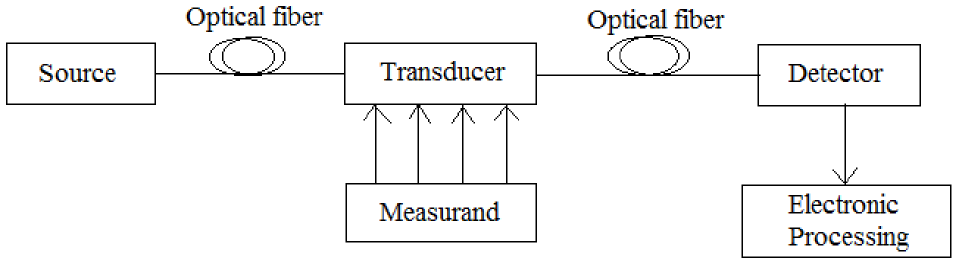

Figure 1 Basic components of fiber optic sensor system

Classification of Fiber optic sensors:

Fiber optic sensors can be classified under three categories:

- The sensing location,
- The operating principle,
- The application.

Depending upon the sensing location, a fiber optic sensor can be classified as extrinsic or intrinsic. In an extrinsic fiber optic sensor (Figure 2), the optical fiber is used to carry light to and from sensing or modulating element. Here optical fiber is used just to carry the optical signal.

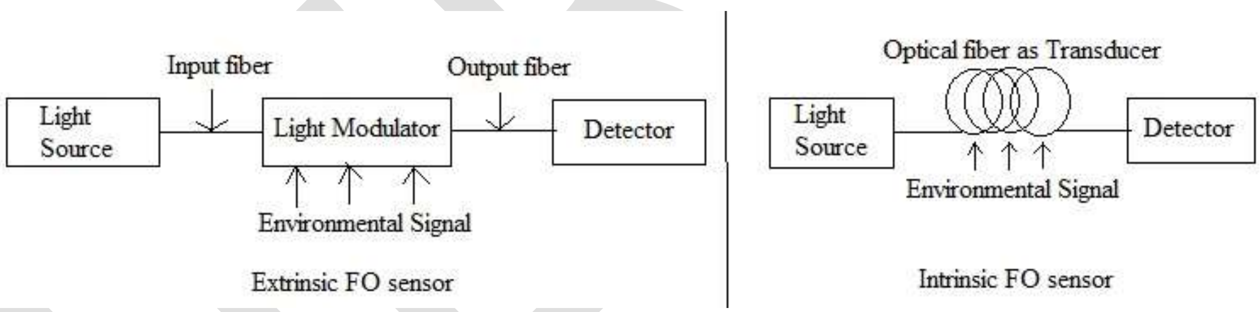

Figure 2 Extrinsic and Intrinsic type of Fiber optic sensors

In an intrinsic fiber optic sensor optical fiber itself acts as a sensor. External perturbations directly act on the fiber which changes the physical properties of the fiber resulting in modulation of the optical properties of the light signal.

Depending upon the operating principle further categories of fiber optic sensors are intensity based, phase modulated, wavelength modulated and polarization modulated fiber optic sensors. External perturbations acting on the optical fiber or the sensing element change the optical properties (intensity, phase, frequency and polarization state) of light signal propagating through the fiber. Therefore, by detecting these properties we can measure the external perturbation.

Based on the application, a fiber optic sensor can be classified as follows:

- Physical sensors: Used to measure physical properties like temperature, stress, etc.
- Chemical sensors: Used for pH measurement, gas analysis, spectroscopic studies, etc.
- Biomedical sensors: Used in bio-medical applications like measurement of blood flow, glucose content etc. [6].

Fiber optic sensor types:

1. Intensity based fiber optic sensors

Signal undergoing some loss is important for Intensity-based fiber optic sensors. These sensors use multimode fibers, as they require more light. A measurand-induced change in the optical intensity can be obtained by micro-bending loss, attenuation, and evanescent fields. The advantages of these sensors are: Easy implementation, low cost, multiplexing capability and real distributed sensing capability [3-6].

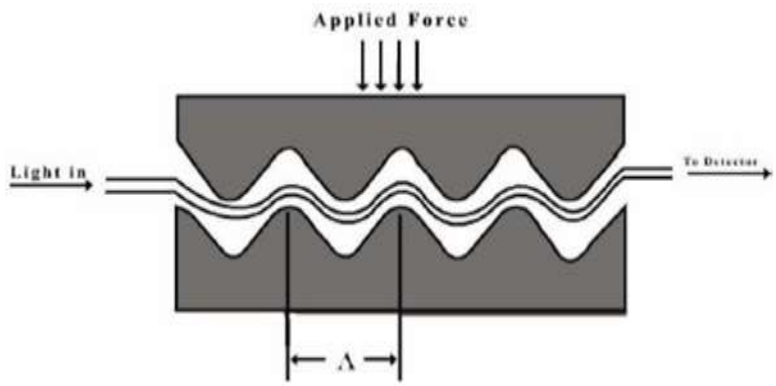

Figure 3 Intensity based Micro-bend sensor

Microbend sensor is one of the intensity-based sensors where mechanical periodic micro bends results in attenuation of the transmitted light. As seen in Figure 3, optical fiber is passed through two grooved plates. In this arrangement, the upper plate can move in response to pressure. When the bend radius of the fiber is more than the critical angle, light starts leaking into the cladding which results in an intensity modulation [6].

2. Wavelength modulated Fiber optic sensors

Changes in the wavelength of light are used for detection in wavelength modulated fiber optic sensors. Examples of wavelength-modulated sensors are Fluorescence sensors, black body sensors, and the Bragg grating sensor.

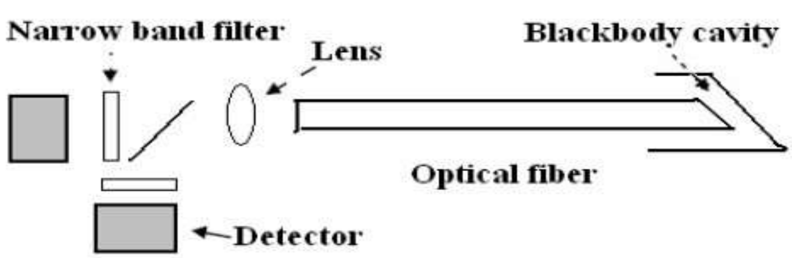

Figure 4. Blackbody Fiber Optic Sensor

The blackbody sensor is the simplest wavelength based fiber optic sensor, as shown in Figure 4[6]. Here, at the end of an optical fiber blackbody cavity is placed. Blackbody cavity starts to glow and act as a light source when its temperature increases. Narrow band filters are combined with detectors to determine the black body curve profile. This type of sensor is used to measure temperature within a few degrees centigrade under intense RF fields.

The Bragg grating sensor is the most widely used wavelength based fiber optic sensor. In a short section of singlemode optical fiber index of refraction of core is periodically changed to form Fiber Bragg gratings (FBGs) which generates a reflection response. In this the measured information is wavelength encoded in the Bragg reflection of the grating. Fiber Bragg grating sensors offer quasi distributed strain measurement and structural health monitoring.

3. **Phase modulated Fiber optic sensors**

Phase modulated sensors detect changes in the phase of light by using interferometric technique. Here phase of light propagating through the signal fiber is compared with the phase of light in a reference fiber. Mach-Zehnder, Michelson, Fabry-Perot, or Sagnac are some of the interferometric techniques. Interferometric technique is used to convert the phase change of optical signal into the intensity change which is detected by the detector. Phase modulated fiber optic sensors are more sensitive than Intensity based fiber optic sensors. These interferometric fiber optic sensors are constructed using single mode optical fiber. These sensors have applications in the areas like military, scientific research and industries.

4. **Polarization modulated Fiber optic sensors**

The direction of the electric field defines the polarization state of the light field. Linear, elliptical and circular are the different types of polarization states of the light field. If the direction of the electric field stays in the same line during the propagation of light, then the polarization state is linear and if the direction of electric field gets altered then the polarization state is elliptical.

Stress or strain on optical fiber changes the refractive index of the fiber which induces the phase difference and changes the output polarization state of the light field passing through the fiber. So, external perturbation are sensed by detecting the change in the output polarization state of the light field.

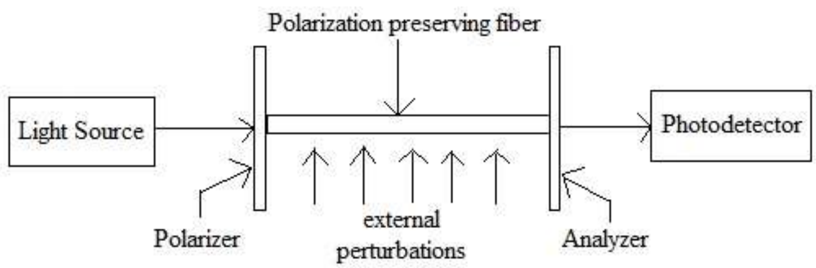

Figure 5 Polarization based Fiber optic sensor

Optical set up for the polarization based fiber optic sensor is as shown in figure 5. The main elements of this sensor are polarizer, polarization preserving fiber and analyser. The polarized light is passed to the sensing element i.e. polarization preserving fiber at specific angle. External perturbation acts on this section where it results into the change of phase difference between two polarization states. The Output polarization state is further analysed and given to the photodetector to detect or measure the external perturbation.

Applications of Fiber optic sensors:

During the late 1970s and early 1980s fiber optic sensors were mainly used for military and aerospace applications only. In 1980s lot of efforts were made for the commercialization of fiber optic sensors with their increasing popularity. In last couple of decades lot of research and development were carried out for precise fiber optic sensors. Now fiber optic sensors have been widely used to monitor a wide range of environmental parameters such as position, vibration, strain, temperature, humidity, viscosity, chemicals, pressure, current, electric field and several other environmental factors [2-6].

Fiber optic sensors are used in:

- Mechanical Measurement such as rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity, viscosity, chemical measurements
- Electrical & Magnetic Measurements
- Chemical & Biological Sensing
- Monitoring the physical health of structures in real time.

- Buildings and Bridges: Concrete monitoring during setting, crack (length, propagation speed) monitoring, spatial displacement measurement, neutral axis evolution, long-term deformation (creep and shrinkage) monitoring, concrete-steel interaction and post-seismic damage evaluation.

- Tunnels: Multipoint optical extensometers, convergence monitoring, shotcrete / prefabricated vaults evaluation, and joints monitoring damage detection.

- Dams: Foundation monitoring, joint expansion monitoring, spatial displacement measurement, leakage monitoring, and distributed temperature monitoring.

- Heritage structures: Displacement monitoring, crack opening analysis, post-seismic damage evaluation, restoration monitoring, and old-new interaction.

- Detection of Leakage in pipelines [7].

Future trends:

Different types of fiber optic sensors were developed and redeveloped with improved size and quality. These advancements and cost reductions gives the promising future to fiber optic sensors. So, the use of fiber optic sensors in various fields along with many niche engineering and biomedical fields will increase with better performance.

Some future trends are as follows:

- For new sensing mechanisms and sensor configurations Special waveguides can be designed.

- Sensor performance, functionality, reliability and capability of harsh environment operation will be improved with improved microfabrication techniques.

- To obtain high density fiber optic sensor networks, advanced signal processing and network technology needs to be designed.

ACKNOWLEDGMENT

We would like to express our special thanks of gratitude to our H.O.D. Dr. P.P. Vaidya and our principal Dr. Mrs. J.M Nair for sharing their pearls of knowledge, wisdom and encouragement. We would also like to thank our family and friends for extending their generous support in the course of work.

CONCLUSION

An overview of fiber optics sensors and their applications has been presented in this paper. Development of high quality fiber optic sensors is possible due to optimizations of components, recent advances and cost reductions. Now fiber optic sensors are replacing traditional electronic sensors, as they are capable of measuring wide range of environmental parameters with better performance. Fiber optic sensors have been successfully applied to many fields such as Military, Medical, Electrical, Civil engineering structures, Gas and Oil industry etc. The future of fiber optic sensors is very promising.

REFERENCES:

[1] "Introduction to Fiber Optics", second Edition, by John Crisp

[2] "Fiber Optic sensors", second edition, by Shizhuo Yin, Paul B. Ruffin, Francis T. S. Yu, CRC Press.

[3] C.R.Batchellor, C.Edge, "Some recent advances in Fibre optic sensors", Electronics & Communication Engineering Journal, Oct 1990.

[4] M. Mahdikhani1 and Z. Bayati, "Application and development of Fiber optic sensors in Civil engineering", The 14th World Conference on Earthquake Engineering, Beijing, China, October 12-17, 2008.

[5] Bahareh Gholamzadeh and Hooman Nabovati, “Fiber Optic Sensors”, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:2, No:6, 2008

[6] Fidanboylu K., Efendioglu H.S., “Fibre Optic Sensors & Their Applications”, 5th International Advanced Technologies Symposium, Turkey, May 2009.

[7] Shaveta Thakral, Pratima Manhas, “Fibre Optic Sensors Technology & their Applications”, International Journal of Electronics & Communication Technology, Vol.2, Issue 2, June 2011.

[8] Venu Gopal, Madhav Annamdas, “Review on Developments in Fibre Optical Sensors & Applications”, International Journal of Materials Engineering 2011; 1(1):1-16.

[9] Dhiraj Ahuja and Deepa Parande, “Optical sensors and their applications”, Journal of Scientific Research and Reviews Vol.1 (5), pp.060-068, November 2012.

[10] “Optical fiber sensors Guide, Fundamentals and Applications”, Micron Optics

[11] “Pipeline Technology Journal”, 2013.

[12] Pipe Patrol Technical Bulletin Articles.

[13] “Fiber Dynamics”(online) Available: www.fiberdynamics.com