A Review on Optical Fiber Sensors and Their Applications

Prof. M. T. Ingle
EXTCDept.
MGI-COETShegaon,India
maheshingle2007@gmail.com

Prof. N. W. Labade
EXTC Dept.
MGI-COET
Shegaon, India
nishantlabade@gmail.com

Prof. R. R. Ambalkar
EXTCDept.
MGI-COET
Shegaon, India
ambalkar.rahul@gmail.com

Abstract—As we know the fiber optics is the evergreen technology in communication but we can make it more efficient by using the fiber optic sensors. Fiber optic sensors are in place of the electrical sensors and used along with the optoelectronics devices.Different types of fiber optic sensors with their applications are explained in this paper.

***Keywords**-OFC,MACH ZENDOR,SAGNAC,MRI*

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I. INTRODUCTION

The Principle of fiber optics was first given by Daniel Colladon and Jacques Babinet in paris in the early 1840.Then it becomes first option as compare to the microware and other electrical system to transmit the data. The performance of any communication system is ultimately limited by the signal-to-noise ratio (SNR) of the received signal and available bandwidth. This limitation can be stated more formally by using the concept of channel capacityintroduced within the framework of information theory [2].Material which were used for fiber optic are plastic and glass, then it was concluded that losses are more in plastic so glass is the best to transmit the data using fiber optic.

With high speed of data transmission fiber optics has also made the progress in optoelectronics component and also its cost reduction makes the new product areas for optical fiber field then the fiber optic sensors has been discovered which is used to sense changes in phase,intensity ,wavelength from outside perturbations on the fiber itself. Fiber optic sensors are also immune to electromagnetic interference,and do not conduct electricity so they can be used in places where there is high voltage electricity or flammable material such as jet fuel. Advantages of fiber optic sensors include their small size and low cost. In contrast to electrical measurements, fiber optic are self-contained, and therefore do not require an external reference signal from a second electrode. Because the signal that is transmitted is an optical signal, there is no electrical risk to the patient and the measurement is immune from interference caused by surrounding electric or magnetic fields. This makes fiber optic sensors very attractive for applications involving intense electromagnetic or radiofrequency fields, for example, near a magnetic resonance imaging (MRI) system or electrosurgical equipment. Chemical analysis can be performed in realtime with almost an instantaneous response.

In section II Principle of OFC is explained .Section III gives the classification of OFC sensors.Section IV Explains the need of OFC and basic components of OFC.Section V explains the types of OFC sensors and section VI gives the applications of OFC sensors. In this paper we know about OFC sensors and its applications

II. PRINCIPLE OF WORKING OF OFC

Fiber optics uses the phenomenon of total internal reflection in which light pulses are used to transfer the information from one point to another .An optical fiber is a dielectric cylindrical waveguide made up of inner medium core and outer medium cladding Shown in figure 1.1

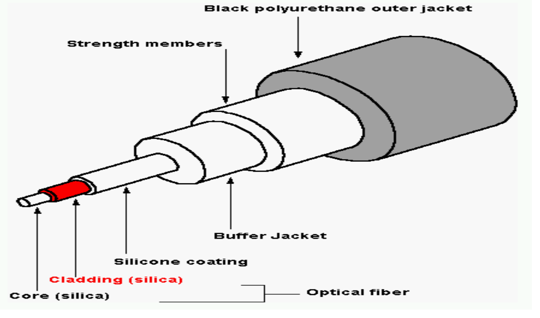

Fig 1.1 Structure of Optical Fiber

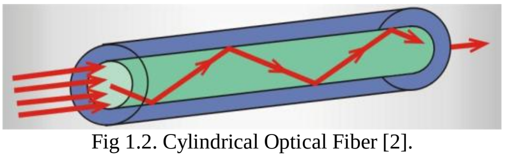

Fig 1.2. Cylindrical Optical Fiber [2].

The refractive index of the cladding is less than the refractive index of core material. These waveguides are made up of loss less material, usually silicon dioxide[3] .The light pulse are travel along the axis of the fiber through total internal reflection. At the transmitter the light signal is transmitted through the optical fiber cable, before transmission the signal is boosted by the optical amplifier and at the receiver side the signal is reconstructed to its original form. The total internal reflection occurs at the core-cladding interface when the light inside the core of the fiber is incident at an angle greater than the critical angle and returns to the core lossless and allows for light propagation along the fiber[2]. The critical angle is determined by Snell's law. The amount of light reflected at the interface changes depending on the incidence angle and the refraction indexes of the core and the cladding. Fig. 1.2 presents the idea of the light propagation in the cylindrical optical fiber due to the total internal reflection.

III. TYPES OF OPTICAL FIBERS

Optical fiber is basically divided in two types.
1. Based on refractive index
2. Based on propagation mode

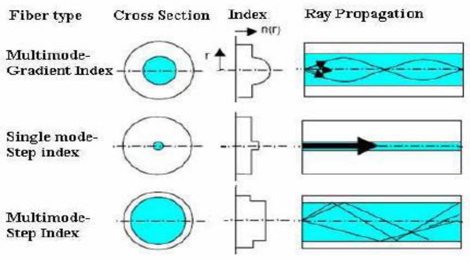

Fig. 3.1 Types of optical fiber

Now based on refractive index it divided in two types
1. Step index fiber
2. Graded index fiber

Based on propagation mode it divided in two types
1. Single mode fiber
2. Multimode fiber

So by combining these two types of fiber they are combinable called
1. Single mode step index fiber
2. Single mode graded index fiber
3. Multimode step index fiber
4. Multimode graded index fiber. [1]

IV. FIBER OPTICS SENSORS

A. *Why Fiber Optic Sensors*

Fiber optic sensors are mostly used because of their following advantages:
(1) very small size, passive and low power; (2)High sensitivity and wide bandwidth;(3)long distance operation (4)Secure data transmission.(5)Resistant to ionizing radiation(6)Can facilitate distributed sensing (7) can work on harsh environment[4,5]

B. *Basic Components of Fiber-Optic sensor System*

As shown in Figure 1, a fiber-optical sensor system consists of an optical source (laser, LED, laserdiode, etc.), optical fiber, sensing or modulator element transducing the measurand to an optical signal, an optical detector and processing electronics (oscilloscope, optical spectrum analyzer, etc.).The advent of laser opens up a new world to researchers in optics. Light sources used to support Fiber-optical sensors produce light that is often dominated by either spontaneous or stimulated emission.

A combination of both types of emission is also used for certain classes of fiber-optical sensors[4].

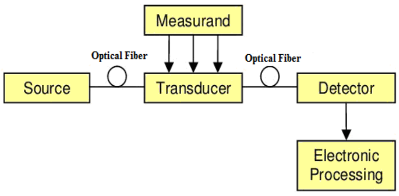

Fig. 4.1 Fiber optics Sensors System [4].

V. CLASSIFICATION OF FIBER OPTICS SENSORS

Table 1. Classification of fiber optics sensors under three categories [4].

Category	Class
sensing location	Point sensors distributed sensors quasi-distributed sensors
operating principle	intensity sensors phase sensors frequency sensors polarization sensors
application	physical sensors chemical sensors bio-medical sensors

Two main types of fiber optic sensors are Intrinsic sensor and extrinsic sensor Furthermore, fiber-optical sensors can also be classified under three categories the sensing location, the operating principle and the application.

A. *Intrinsic And Extrinsic Optical Sensors*

The light rays are changed either outside or inside of the fiber optic cable. Based on this fact, there are two types extrinsic and intrinsic. In this type, light rays do not come out of fiber cable. They get changed inside the cable itself. One such application is shown in the figure 5.1 where in due to pressure applied between the two plates will change the light beam and hence pressure is measured.When light beam leaves the fiber cable and get changed due to object before it reaches to the optical detector end then it is known as extrinsic optical sensor shown in figure 5.2. The distance L can be measured with this type of optical sensor as shown [3].

In intrinsic FOSs, the optical fiber structure is modified and the fiber itself plays an active role in the sensing function, i.e. modulation of light takes place inside the fiber to measure a particular parameter. So they are also called all-fibersensors.Extrinsic optical sensors are found in Fabry-Perot interferometers which uses very few advantages of optical fibertechnology.Intrinsic optical fiber uses most of the advantages provided by the optical fibertechnology.The types of intrinsic sensors are gyroscope,fiber brass gratings,long period gratings,microbend and coated or doped fiber.

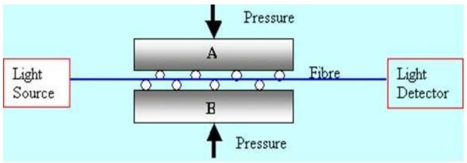

Fig. 5.1 Intrinsic Fiber Optic Sensor [3]

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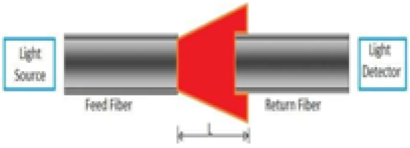

Fig. 5.1 Extrinsic Fiber Optic Sensor [3]

B. *Intensity Moduated Fiber Optic sensors*

Intensity modulation is the simplest and the cheapest way of detecting or measuring different parameters. In intensity modulated fiber optic sensors, the measurand modulates the intensity of the transmitted light through the fiber and these variations in intensity are measured using a detector situated at the output end ofthe fiber. These fiber optic sensors offer the easiest method of implementation and compatible with the multimode fiber technology. The intensity modulation can be achieved in a variety of methods [6].The intensity modulated sensors are simple and low in cost. These fiber uses multimode large core fiber because of more light requirement .Displacement of one fiber relative to another(or misalignment of one fiber with respect to other fiber) through light interruption results in intensity modulation .The intensity modulation can be achieved by two sensors[1,6].

1.Microbend sensor

This technique is mainly used for the measurement of acoustic pressure, strain, temperature, displacement etc. Here the fiber may be sandwiched between a pair of toothed or serrated plates to induce microbending as shown in figure 5.2.There is a coupling between guided and continuum of cladding modes, which results in irreversibly leak of the optical power from the fiber. The micro bend sensitivity can be enhanced by the proper constriction of deformer plates

2. Even scent wave sensor

Evanescent field absorption spectroscopy is a powerful well-established laboratory technique for chemical analysis for detection of nitrite, ammonia traces in water. There are two approaches which have been adopted in these sensors. In one of the approach, if the wavelength of the light propagating coincides with the absorption band of analyte, then the evanescent wave can interact directly with the analyte. Sensors using such approach are called direct spectroscopic evanescent wave sensors. In the other approach, an intermediate reagent which responds optically to the analyte is attached to the core of the fiber. Sensors using such approach are called reagent-mediated evanescent wave sensors. In my project, I am using the first approach in which one of the media is waveguide having a thin cylindrical non absorbing crystal and other medium is the absorbing sample under study of lower refractive index. The degree of absorption depends on the amplitude of the evanescent field in the sample medium and the number of reflections within the waveguide. Design of evanescent field absorption based sensor devices requires knowledge about certain parameters such aspenetration depth (dp), total power in the fiber, bulk absorption coefficient etc. These design parameters play a crucial role in determining the sensitivity, absorption coefficient, power in cladding etc.of fiber optic sensors [7].

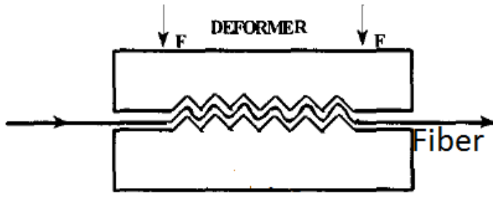

Fig.5.2 Microbend Sensor [6]

C. *Phase Modulated Fiber Optic sensors*

This method is based on the variation in optical phase or modulation in optical phase and the total phase is depend on the other characteristics of optical fiber like refractive index ,physical length of the fiber, index profile of the waveguide. The phase change occurring in an optical fibre is detected using optical fibreinterferometric techniques that convert phase modulation into intensity modulation. There are a variety of fibre optic interferometers like Mach-Zehnder,Sagnac and Fabry-Perot as shown in figure 5.3 to 5.5. The fiber optic interferometers are having high range of application like in industries, military applications etc. They are not sensitive to the external disturbunces like conventional interferometers[6].

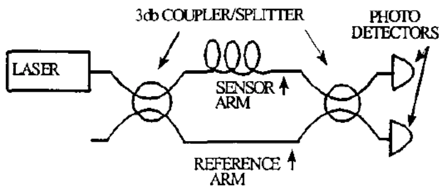

Fig.5.3 MACH ZENDOR [6].

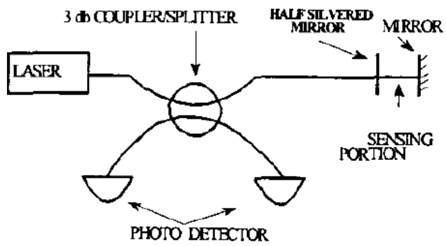

Fig. 5.4 FABRY PEROT [6].

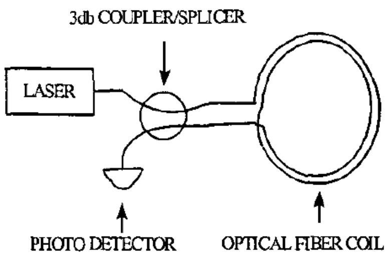

Fig.5.5 SAGNAC [6].

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D. Wave Modulated Fiber Optic Sensors

Wavelength modulated sensors use changes in the wavelength of light for detection. Truly wavelength-modulated sensors are those making use of gratings
inscribed inside the optical fiber. A grating is a periodic structure that causes light or incident electromagnetic energy to behave in a certain way dependent on the periodicity of the grating. Fluorescence sensors, black body sensors, and the Bragg grating sensor are examples of wavelength-modulated sensors.

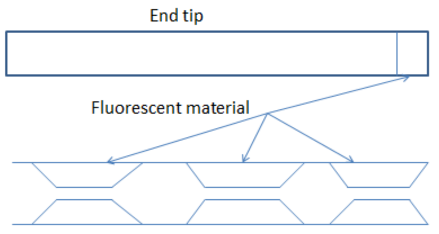

Fig. 5.6 Fluorescence Wave Sensor [1].

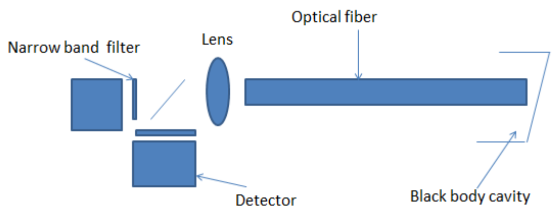

Fig. 5.7 Blackbody sensor [1].

Figure 5.6 shows the fluorescence wave fiber optic sensor. It is made up of fluorescent material. The end tip sensor, light propagated down the fiber to a probe of fluorescent material. The resultant signal is captured by the same fiber and directed back to an output demodulator.[1]

Another the simplest wavelength based sensor is the blackbody sensor as shown in Figure 5.7. A blackbody cavity is placed at the end of an optical fiber. When the cavity rises in temperature it starts to glow and act as a light source. Detectors in combination with narrow band filters are then used to determine the profile of the blackbody curve. This type of sensor has been used to measure temperature to within a few degrees centigrade under intense RF fields.[1]

E. Fiber Optic Chemical Sensors

A chemical sensor is a device that can be used to measure the concentration or activityof a chemical species in a sample. The qualities like chemical inertness, low weight andsmall volume of optical fibres along with advantages like immunity to electromagneticinterference and easy availability have promoted the research and developmentalactivities in the area of fibre optic chemical sensors (FOCSS). Hence this optical transduction allows a wide variety of chemical detection schemes that werepreviously impossible using conventional potentiometric and amperometric electrochemicaldevices [6]. The most commonly found fiber optic chemical sensor (FOeS) designs are,

1. Distal-type probes in which the indicator is immobilised at the tip of a bifurcated fiber optic bundle or single optical fiber.
2. Evanescent field type

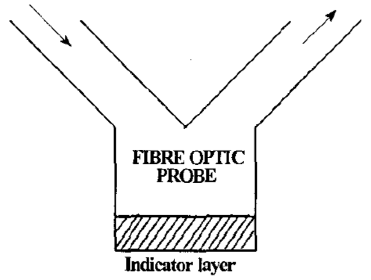

Fig. 5.8 Distal Type Probes[6].

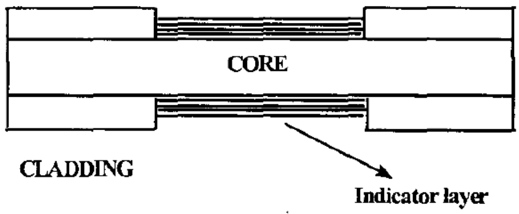

Fig. 5.9 Evanescent Wave Type[6]

VI. APPLICATIONS OF FIBER OPTIC SENSORS

- Measurement of physical properties such as strain, displacement, temperature, pressure, velocity, and acceleration in structures of any shape or size.
- Buildings and Bridges: Concrete monitoring during setting, crack (length, propagation speed) monitoring, prestressing 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, prefabricated vaults evaluation, and joints monitoring damage detection.
- Monitoring the physical health of structures in real time.
- 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.[1]

VII. CONCLUSION

There is huge demand of Fiber Optic Sensors in market. As per the applications different types of fiber optics sensors are available and the mostly used sensors are intrinsic, extrinsic, Mach Zehnder interferometer, fiber Bragg grating sensor, fiber optic gyroscope sensor and their practical use in chemical or biomedical field.

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