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Fiber Optic Sensors and Their Applications

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***Abstract*— Beside advantages;recent advances technology and cost reductions has stimulated interest in fiber optical sensing. So, researchers combined the product of fiber optic telecommunications with opto electronic devices to emerge fiber optic sensors. Numerous researches have been conducted in past decades using fiber optic sensors with different techniques. Intensity, phase, and wavelength based fiber optic sensors are the most widely used sensors. In this paper, an overview of fiber optic sensors and their applications are presented.**

***Index Terms*— Fiber optics, optical fiber sensing, fiber sensor application.**

I. INTRODUCTION

With the invention of the laser in 1960's, a great interest in optical systems for data communications began. Laser systems could send a much larger amount of data than microwave, and other electrical systems. Glass fibers soon became the preferred medium for transmission of light. Initially, the existence of large losses in optical fibers Prevented coaxial cables from being replaced by optical fibers.

In 1969, several scientists concluded that impurities in the fiber material caused the signal loss in optical fibers. By removing these impurities, construction of low-loss optical fibers was possible. In 1970, Corning Glass Works made a multimode fiber with losses under 20 dB/km . The same company, in 1972, made a high silica-core multimode optical fiber with a 4 dB/km loss.

The optoelectronics industry has brought about such products as compact disc players, laser printers, bar code scanners and laser pointers. The fiber optic communication industry has literally revolutionized the telecommunication industry by providing higher performance, more reliable tele communication links with ever decreasing bandwidth cost.

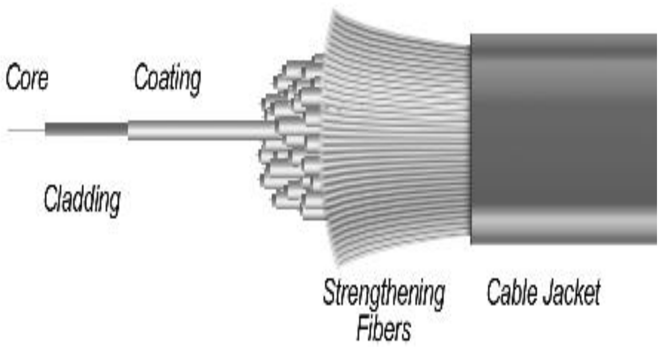
In parallel with these developments, Fiber optic sensor technology in turn has often been driven by the development and subsequent mass production of components to support these industries. As component prices have decreased and quality improvements have been made, the ability of fiber optic sensors to replace traditional sensors have also increased.

Fiber optic sensors are excellent candidates for monitoring environmental changes. So 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 and they offer many advantages over conventional electronic sensors as listed below:

- Easy integration into a wide variety of structures, including composite materials, with little interference due to their small size and cylindrical geometry.
- Inability to conduct electric current.
- Immune to electromagnetic interference and radio frequency interference.
- Lightweight.
- Robust, more resistant to harsh environments.
- High sensitivity.
- Multiplexing capability to form sensing networks.
- Remote sensing capability.
- Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals.

II. OPTICAL FIBER BASICS

An optical fiber is composed of three parts; the core, the cladding, and the coating or buffer. The basic structure is shown in Figure. The core is a cylindrical rod of dielectric material and is generally made of glass. Light propagates mainly along the core of the fiber.



The cladding layer is made of a dielectric material with an index of refraction. The index of refraction of the cladding material is less than that of the core material. The cladding is generally made of glass or plastic. The cladding executes such functions as decreasing loss of light from core into the surrounding air, decreasing scattering loss at the surface of the core, protecting the fiber from absorbing the surface contaminants and adding mechanical strength.

The coating or buffer is a layer of material used to protect an optical fiber from physical damage. The material used for a buffer is a type of plastic. The buffer is elastic in nature and prevents abrasions.

The light-guiding principle along the fiber is based on the "total internal reflection". The angle at which total internal reflection occurs is called the critical angle of incidence. At

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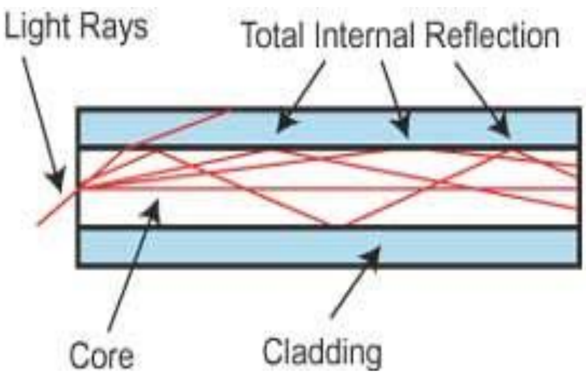
any angle of incidence, greater than the critical angle, light is totally reflected back into the glass medium . The critical angle of incidence is determined by using Snell's Law.



III. Fiber Optic Sensor Principles

The general structure of an optical fiber sensor system is shown in Figure 4. It consists of an optical source (Laser, LED, Laser diode etc), optical fiber, sensing or modulator element (which transduces the measurand to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc).

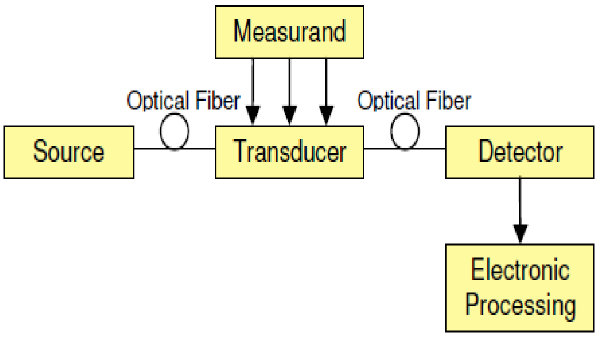


Figure 4. Basic components of an optical fiber sensor system.

Fiber optic sensors can be classified under three categories: The sensing location, the operating principle, and the application. Based on the sensing location, a fiber optic sensor can be classified as extrinsic or intrinsic. In an extrinsic fiber optic sensor the fiber is simply used to carry light to and from an external optical device where the sensing takes place. In this cases, the fiber just acts as a means of getting the light to the sensing location.

On the other hand, in an intrinsic fiber optic sensor one or more of the physical properties of the fiber undergo a change . Perturbations act on the fiber and the fiber in turn changes some characteristic of the light inside the fiber .

Based on the operating principle or modulation and demodulation process, a fiber optic sensor can be classified as an intensity, a phase, a frequency, or a polarization sensor. All these parameters may be subject to change due to external perturbations. Thus, by detecting these parameters and their changes, the external perturbations can be sensed .

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.
• Bio-medical sensors: Used in bio-medical applications like measurement of blood flow, glucose content etc.

IV. Fiber Optic Sensor Types

A. *Intensity Based Fiber Optic Sensors*

Intensity-based fiber optic sensors rely on signal undergoing some loss. They are made by using an apparatus to convert what is being measured into a force that bends the fiber and causes attenuation of the signal.

The intensity-based sensor requires more light and therefore usually uses multimode large core fibers . The advantages of these sensors are: Simplicity of implementation, low cost, possibility of being multiplexed, and ability to perform as real distributed sensors. The drawbacks are: Relative measurements and variations in the intensity of the light source may lead to false readings, unless a referencing system is used.

One of the intensity-based sensors is the microbend sensor, which is based on the principle that mechanical periodic micro bends can cause the energy of the guided modes to be coupled to the radiation modes and consequently resulting in attenuation of the transmitted light. Another type of intensity based fiber optic sensor is the evanescent wave sensorthat utilizes the light energy which leaks from the core into the cladding. These sensors are widely used as chemical sensors.

B. *Wavelength Modulated Fiber Optic Sensors*

Wavelength modulated sensors use changes in the wavelength of light for detection. Fluorescence sensors, black body sensors, and the Bragg grating sensor are examples of wavelength-modulated sensors. Fluorescent based fiber sensors are being widely used for medical applications, chemical sensing and physical parameter measurements such as temperature, viscosity and humidity. One of the simplest wavelength based sensor is the blackbody sensor. The most widely used wavelength based sensor is the Bragg grating sensor.

C. *Phase Modulated Fiber Optic Sensors*

Phase modulated sensors use changes in the phase of light for detection. The optical phase of the light passing through the fiber is modulated by the field to be detected Mach-Zehnder, Michelson, Fabry-Perot, Sagnac, polarimetric, and grating interferometers are the most commonly used intereferometers. Another commonly used interferometer based sensor is the Fabry-Perot interferometric sensor (FFPI) and this is classified into two categories: Extrinsic

Fabry-Perot interferometer (EFPI) sensor and intrinsic Fabry-Perot interferometer (IFPI) sensor. Sagnac interferometric sensors are based on fiber gyroscopes that can be used to sense angular velocity. Two types of fiber optic gyros have been developed: Open loop fiber optic gyro and closed loop fiber optic gyro.

D. Polarization Modulated Fiber Optic Sensors

The direction of the electric field portion of the light field is defined as the polarization state of the light field. Different types of polarization states of the light field are linear, elliptical, and circular polarization states. For the linear polarization state, the direction of the electric field always keeps in the same line during the light propagation. For the elliptical polarization state, the direction of the electric field changes during the light propagation. The refractive index of a fiber changes when it undergoes stress or strain. Thus, there is an induced phase difference between different polarization directions.

V. Applications of Fiber Optic Sensors

Fiber optic sensors are used in several areas. Specifically:

• Measurement of physical properties such as strain, displacement, temperature, pressure, velocity, and acceleration in structures of any shape or size.

• Monitoring the physical health of structures in real time.

• 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, 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.

VI. Conclusions

An overview of fiber optics sensors and their applications has been presented. The major types of sensors discussed included micro bending sensors, evanescent wave sensors, FBGs, optical fiber interferometers and polarization modulated fiber optic sensors.

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