Distributed Optical Fiber Sensor and Its Various Applications

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Abstract: ***The process of sensing can also be done with the help of optical fiber. This method of sensing is becoming very popular. The optical communication, which is the main communication technology, in this case, takes light as the carrier and optical fiber as the communication medium. Distributed Optical Fiber Sensors (DOFS) can be used for continuous measurement at the same time to obtain the spatial distribution of the measured state and time-varying information. This paper describes the background of DOFS technology. Various applications of DOFS are also listed.***

Keywords: Distributed Optical Fiber Sensor (DOFS), Fiber Bragg Grating (FBG), Structural Health Monitoring (SHM)

1. Introduction

We can use the process of multiplexing, where there are multiple numbers of inputs and a single output, to increase the function ability of the optical fiber sensor [1]. A common optoelectronic terminal can be used, thereby reducing the cost to a very large amount. In a distributed sensor, the sensor consists of a single length of the fiber cable and the optoelectronic terminal can monitor the variation of a physical parameter such as temperature, pressure, water level etc. In a Distributed Optical Fiber Sensor (DOFS), this sensing should be a continuous process. Distributed sensing replaces the complex integration of thousands of sensor with one optical fiber system. The inherent distributed sensing nature of fiber-optic sensors can be used to create unique forms of sensors for which, in general, there may be no counterpart based on conventional sensor technologies. The basic advantage of optical fiber is that it is cheap, light, pliable and are immune to Electro-Magnetic Interference (EMI). This is an inherent sensor medium with low cost, inertness and flexibility. The fiber is a flexible, insulating, dielectric medium, which can be readily installed in an industrial plant without significant disturbances of the measurement environment [2,12].

2. Working Principle and Measuring Techniques

Temperature, pressure and tensile strength etc. change the characteristics of light transmission in a fiber. A damping or attenuation is caused by these external physical parameters and their exact location can be found out by the method of scattering. Thus, the optical fiber can be employed as a sensor. The quartz that consists of SiO_2 is the basic component of optical fiber. Any variation in the external parameter will induce some oscillations in the structure. When light falls onto these thermally excited molecular oscillations, an interaction occurs between the light particles (photons) and the electrons of the molecule, thereby causing a phenomenon known as the Raman Scattering. This scattered light from the optical fiber consists of three different components as mentioned below [3]:

(i) **Rayleigh Scattering Component**: It is the dominant component that has the frequency, same as the frequency of the laser source being used in the system.

(ii) **Stokes Line Component**: This component consists of lower frequency optical signals than the Rayleigh scattered component.

(iii) **Anti-Stokes Line Component**: This component consists of higher frequency optical signals than the Rayleigh scattered component.

3. Measurement Methods

For the measurement of different scattered components in a DOFS, we can basically use three methods:

(i) Optical Time Domain Reflectometry (OTDR): This was developed more than 20 years ago. Here, a narrow laser pulse generated by a semiconductor or solid-state laser is sent into the fiber and the back-scattered light is analyzed. From the time duration that it takes the back-scattered light to return to the detection unit, it is possible to locate the origin of the external physical parameter such as increase or decrease in temperature, pressure, tensile force etc.

(ii) Optical Frequency Domain Reflectometry (OFDR): Here, the back-scattered light is measured as a function of frequency and Fourier transformation is used.

(iii) Code Correlation Optical Time Domain Reflectometry (CC-OTDR): Here, binary Coley Code is used and the optical energy is spread over a code rather than packed into a single pulse.

4. Basic Structure of a DOFS System

DOFS basically, consists of a controller, laser source, and pulse generator for OTDR or CC-OTDR, modulator, high frequency (HF) mixer for OFDR, optical module, receiver, microprocessor unit and a quartz glass fiber as a sensor medium.

5. Various Applications of DOFS

There are numerous applications of Distributed Optical Fiber Sensor (DOFS) network including monitoring of embankment dams, pipeline leakage detection, habitat monitoring and structural health monitoring etc. Various applications are listed below:

(a) ***Monitoring Embankment Dams***: The usual method of monitoring of embankment dams uses the pneumatic piezometers that measure the gas pressure and the readings are taken weekly in a manual manner. The sunlight will cause severe damage to the piezoelectric component. These problems can be solved by the fiber optic sensor. A fiber optic sensor system based on fiber bending loss and optical time domain reflectometry (OTDR) can be used for monitoring of embankment dams [4]. This system uses an OTDR module that sends pulses to the distributed sensors placed in the embankment dams. The attenuation of the reflected pulses due to the external pressure is measured that will give the level of water penetration in the embankment dams.

(b) ***Pipe Line Leakage and Intrusion***: It is always a problem to monitor or check the underground pipe line leakage, tampering and overload of any form. A distributed optical fiber sensor (DOFS) was proposed to monitor the pipe line leakage and intrusion that is based on Code Correlation OTDR (CC-OTDR) that uses the Golay Codes. The transmitted and the reflected optical power are correlated and the loss is obtained. This loss is sensitive to the soakage of the hydrocarbon fuels and the intrusion such as tampering, overload, impacting etc. The CC-OTDR improves the range of frequency that can be analyzed and also improves the signal to noise ratio compared to the conventional OTDR [5].

(c) ***Virtual Monitoring of Rotor Temperature***: Rotor temperature of a turbine has a direct relationship with the turbine's safe running and safety. A Distributed Optical Temperature Sensor (DOFS) is used to obtain the overall temperature of the rotor rather than the temperature of a particular place by using a single sensor. This is a low cost, more convenient, fast and high precision method compared to the single sensor method. The Laboratory Virtual Instrument Engineering Workbench (LabView) software can be used for virtual monitoring of the rotor temperature [6].

(d) ***Power System Temperature Monitoring***: The Distributed optical fiber Temperature Sensor (DTS) uses the Raman scattering effect. This technique is a continuous method to monitor the temperature that can operate safely in the dangerous power system environment. When the temperature of the power station exceeds the set value, an alarm signal will be sending out. Two engineering project work of China are monitored by this method where they use the temperature set point at 78°, after which the alarm signal will be sent out [7].

(e) ***Measurement of Structural Strain***: The Brillouin optical time-domain reflectometer method can be used to monitor structural strain. This method can measure strain at points along continuous lengths of the optical fiber of up to 10 km and more. Whenever there is a fault in a civil structure, this method can provide an effective warning measure [8]. This method uses a nonwoven cloth that can detect soil movements of a few millimetres in soil structure.

(f) ***Smart Sensor for SHM***: A smart transducer interface module is developed that is made up of 2 optical fiber PIN receiver, a differential amplifier and a digital signal processor. The

DSP unit consists of an in build analog to digital converter (ADC). Here [9], a smart transducer interface module (STIM) for Fiber Bragg Grating (FBG) sensor to realize Optical Fiber Sensor (OFS) is developed. Typically, FBGs are used as spectral transduction elements due to the absolute nature of spectral encoding and immunity to optical power fluctuation. FBGs have several characteristics such as small size, small weight, immune to the electromagnetic effect, versatility to detect various physical measurands. These characteristics make FBGs very much reliable for structural health monitoring (SHM). Acoustic emission, actively generated acoustic-ultrasonic signal, dynamic strain (e.g. vibration), static strain (load monitoring), and corrosion, etc. come under SHM.

(g) ***DTS with Optical Switch***: Distributed optical fiber temperature sensor (DTS) is a real-time, online, continuous optical fiber temperature measurement system. It has become a new detection method and technology for the field of public safety and industrial process monitoring. In DTS, the length of the sensing optical fiber is determined by the power of laser pulse, loss coefficient and Signal to Noise Ratio (SNR) of the system. By the introduction of optical switch, we can extend the sensing length of the system [10]. The high-frequency anti-Stokes Raman scattering signal in optical fiber is modulated by spatially distributed temperature field while the Stokes Raman scattering signal is not. Temperature value at any point along the optical fiber can be calculated by using Stokes Raman scattering signal to demodulate anti-Stokes Raman scattering signal. DTS is based on this concept. The temperature is calculated out by the ratio of anti-Stokes Raman and Stokes Raman signals.

(h) ***DTS for Hydrologic System***: Hydrologic processes are strongly influenced by interacting processes that span spatial scales from centimetre to kilometres, presenting profound challenges for description, modelling and observation. By placing many sensor nodes spaced along the distance, it would be possible to observe hydrologic processes.

(i) ***Audible Frequency Sensor***: After the discovery of Cole and Bruno in the year 1977, that sound can be detected by the optical fiber; many types of research are going on in this field. A Distributed Optical Fiber Sensor (DOFS) has been demonstrated that uses in-phase Optical Time Domain Reflectometer (OTDR) technique to detect acoustically generated perturbation along the sensing fiber. The result shows that this technique can measure both the frequency and the amplitude of multiple perturbations. We can also use a Chebyshev window in the signal processing procedure to improve the Signal to Noise Ratio (SNR) value.

(j) ***Vibration Sensor***: An Optical Time Domain Reflectometer (OTDR) is developed to achieve high-frequency response and wide spatial resolution. Pencil-break event is tested as a vibration source. OFDR can also be used for vibration sensing. A distributed vibration sensing system based on all polarization-maintaining configurations of the phase sensitive OTDR can be presented.

6. Conclusion

Distributed Optical Fiber Sensors (DOFS) is a new technology where the transmission medium itself acts as a sensor. This technique can be used to detect various faults in the civil structures, leakage in the buried pipelines, the pressure exerted in a device, frequency, vibration etc. It is gaining very wide use due to its low cost and immunity towards electromagnetic interference. This paper discusses the characteristics of DOFS and its various applications.

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