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Brillouin backscattered power a measure for sensing strain in civil structures due to displacement of optical fiber

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Abstract— **In this paper the application of Brillouin Scattering for monitoring strain along the fiber is carried out by designing a strain sensor. Inside the fiber the photons interact with the fiber molecules and cause some changes in the propagation of light. The backscattered light spectrum contains three types of light signal namely; the Rayleigh backscattered light, the Brillouin backscattered light and the Raman backscattered light. The backscattered optical signals carries much information on the variation of strain in the path of wave propagation. The Brillouin backscattered light signal power can be used to obtain information about the strain distribution along the fiber. The changes in Brillouin backscattered light signal is effective in detecting the strain changes in the surrounding. In this paper the application of Brillouin Scattering for strain monitoring is performed. Detailed designing of a strain sensor for application in civil structures is done to validate the proposed method using the OptiSystem software.**

Keywords— Brillouin effect; strain; fiber optic; sensor; civil structures; Optical time domain reflectometry

I. INTRODUCTION

Sensors that are developed using optical fiber are being extensively utilized in various fields as compared to conventional sensing technologies. It has some remarkable properties such as immunity to electromagnetic interference, ability to function in hostile environments and has high sensitivity. These unique characteristics of fiber optic sensors provides accurate detection of cracks and strain in different civil structures. This makes it applicable to be utilized in the study of structural health monitoring. It is important to keep a track of the conditions massive structures in civil infrastructure construction fields that are usually made of concrete. Regular monitoring and evaluation of different kinds of civil structures is needed in order to avoid mishaps [1]. There are many sensing technologies that implement varied technologies like electrical and mechanical. But the optical approaches have advantages over those technologies. Fiber optic based sensors are the only sensors that can fulfill the accuracy required to detect the location of crack [2].

The Brillouin scattering based optical fiber sensor can realize fully distributed strain and temperature measurement along the fiber, which provides a convenient way for health monitoring on the large civil structures, such as dams, bridges, pipe lines, and tunnels, for which long sensing length is required to cover the entire structures in 2D or 3D. Therefore, this has gained extensive attention and many Brillouin systems based on optical time-domain reflectometry (OTDR) are developed in recent years [3-13].

II. BRILLOUIN BACKSCATTERING AND ITS FREQUENCY SHIFT DUE TO STRAIN :

Sensors based on the Brillouin effect are due to the inelastic interaction of the light propagating in the core with acoustic phonons. The metrological interest is in the dependence of the shift with strain (1 MHz / 20 μm/m) and temperature (~ 1 MHz/°C)[14].

The structural monitoring system based on optical fiber may monitor the strain along the fiber and corresponding damage points in the structures. Moreover, it may determine the load distribution, strain levels or temperature profiles, internal damages, and trigger alarm if measurements exceed predetermined thresholds [15-17].

Brillouin based strain sensors have been useful in recent years, with applications in many industrial sectors. Brillouin systems are based on optical time-domain-reflectometry (OTDR) [18, 19].

Fig.1 Backscattered Signal

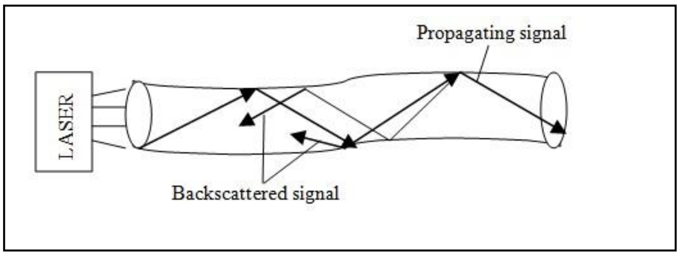


Figure 1 shows how some amount of propagating light get backscattered. Some amount of light wave get backscattered due to various factor.

Fig.2 Frequency shift of Brillouin signal due to Strain

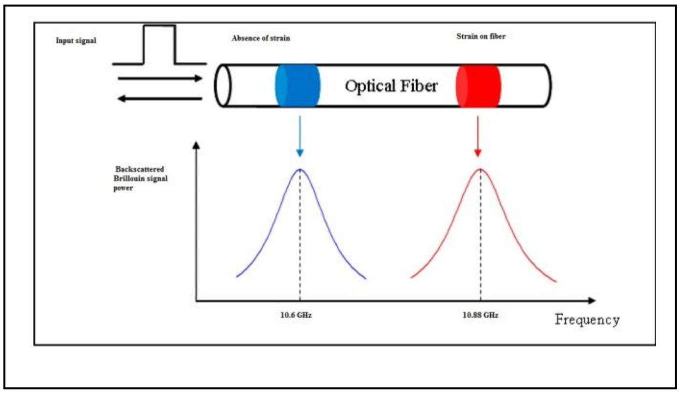


Figure 2 depicts how there is shift in Brillouin frequency whenever there is strain on the fiber.

III. Optical Kit For Angular Displacement

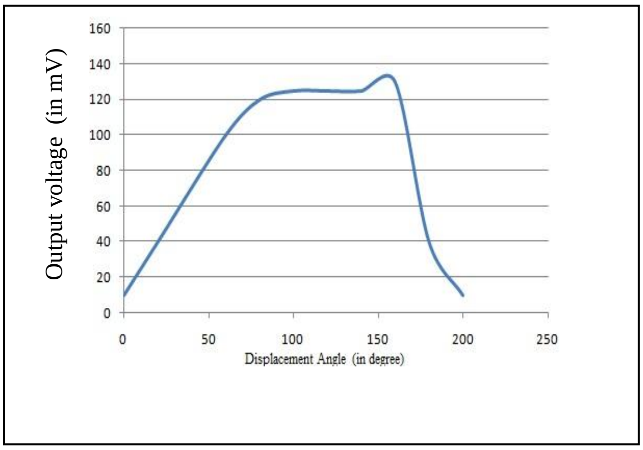
Fig.3 Optical Kit to Study Displacement

In Figure 3 the optical kit is used to study the angular displacement. A multimode fiber of 125micro meter diameter is used. A light from the source is focused using a microscope into one end of the fiber. Then at the other end the output voltage is measured using a multi meter. The angle of the detector is changed and the corresponding changes in voltage is found and noted. A graph of angular displacement versus voltage at output end is drawn.

TABLE I: Changes in voltage at output end of fiber with variation in Displacement Angle

Displacement Angle (in degree)	Voltage at output end of fibre (in mV)
0	10
20	40
60	100
80	120
100	125
120	125
140	125
160	130
180	40
200	10

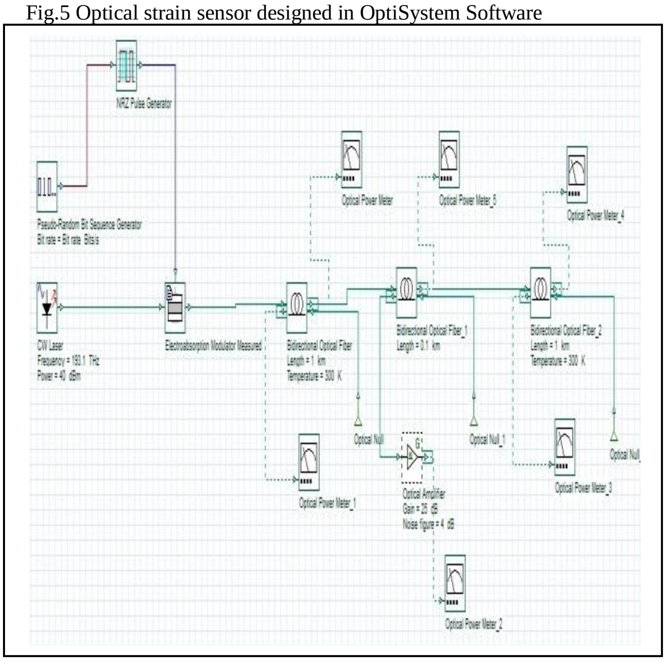
Fig.4 Displacement Angle versus Strain percentage



The Figure 4 is the graph showing angular displacement versus voltage at output end of fiber set up in the optical kit. As the displacement angle changes from 0 to 80 degree the out put voltage changes from 0 to 120 milli volt. As the displacement angle changes from 100 to 140 degree the out put voltage is 125 milli volt. As the displacement angle changes from 160 to 200 degree the out put voltage changes from 130 to 10 milli volt.

IV. SYSTEM DESIGN CONSIDERATION

Fig.5 Optical strain sensor designed in OptiSystem Software



In the Figure 5 there is digital signal as input data that is represented which has been generated by a Pseudo-Random Bit Sequence (PRBS) Generator. This signal is then fed to a non-return-zero (NRZ) pulse generator. Then the input signal is modulated with a Continuous Wave (CW) laser through Electroabsorption modulator. CW laser gives carrier signal with frequency of 193.1THz and input power of 40dBm. It is externally modulated with a non-return-zero (NRZ) pseudorandom binary sequence in a modulator. In OptiSystem bidirectional optical fiber is used so that any changes in the backscattered power can be noted. Optical null is taken in one of the port in the design. The optical power meters are used to analyze the power changes due to the change in strain at the surroundings of the fiber.

TABLE II: Simulation parameters

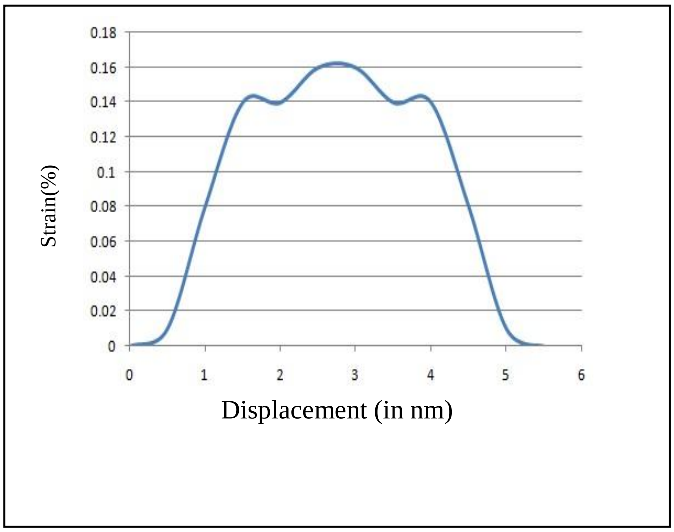
Component	**Specification**
CW LASER	Power : 40 dBm
Bidirectional optical fiber	Length: 1km; Temp: 300K
Bidirectional optical fiber_1	Length: 0.1km; Temp: 300K
Bidirectional optical fiber_2	Length: 1km; Temp: 300K
Optical amplifier	Gain:25 dB

V. SIMULATION OF THE SYSTEM

A Pseudo-Random bit sequence generator is connected to a NRZ pulse generator. A Laser source of 40dBm is considered. The CW Laser as well as NRZ pulse generator are connected to a Electroabsorption modulator. Then modulator is connected to fiber spools. Three bi-directional fiber spools of length 1km, 0.1 km and 1km are connected to each other respectively. The ports are connected to optical power meter and optical nulls. The middle fiber spool is connected to an optical amplifier with gain of 25dB. The strain on the middle fiber spool is varied. The corresponding Brillouin backscattered power is found and the displacement calculated.

TABLE III: Tabulation of changes in Brillouin Power and Displacement due to strain

Displacement in middle fiber spool (in nanometers)	**Strain in middle fiber spool (%)**	**Brillion Backscattered power in middle fiber spool (in mW)**
0	0	209.799
0.5	0.01	210.488
1	0.08	220.176
1.5	0.14	230.863
2	0.14	250.548
2.5	0.16	260.617
3	0.16	310.327
3.5	0.14	314.936
4	0.14	260.880
4.5	0.08	240.445
5	0.01	245.889
5.5	0	230.390



VI. Results and Discussion

Fig.6 Displacement versus Strain percentage

In the Figure 6 there is graph of the displacement in fiber versus the strain percentage on it. Therefore whenever there is displacement in fiber the Brillouin backscattered signal changes and the corresponding change in strain can be measured. Thus strain sensing is possible by studying the Brillouin backscattered light.

VII Conclusion

The changes in Brillouin backscattered power has been noted. It is found that due to strain on the middle fiber spool there is displacement in fiber for the designed model of the strain sensing in optical system**.** It is observed that strain percent increases then the displacement increases. The graph of strain percentage versus displacement shows that due to slight changes in strain there is displacement in the fiber which corresponds to the damage points in the structure.

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