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빌딩표면에 분포된 온도를 측정하기 위한 광섬유 BOTDA 센서의 적용

Application of fiber optic BOTDA sensor for measuring the temperature distributed on the surfaces of a building

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ABSTRACT

We have focused on the development of a fiber optic BOTDA (Brillouin Optical Time Domain Analysis) sensor system in order to measure temperature distributed on large structures. Also, we present a feasibility study of the fiber optic sensor to monitor the distributed temperature on a building construction. A fiber optic BOTDA sensor system, which has a capability of measuring the temperature distribution, attempted over several kilometers of long fiber paths. This simple fiber optic sensor system employs a laser diode and two electro-optic modulators. The optical fiber of the length of 1400 m was installed on the surfaces of the building. The change of the distributed temperature on the building construction was well measured by this fiber optic sensor. The temperature changed normally up to 4 °C through one day.

KEYWORDS: Structural Health Monitoring, Distributed Temperature, Fiber Optic BOTDA Sensor, Building Construction

INTRODUCTION

Fiber optic sensors for the application of smart structures have many advantages in that they are easy to be embedded in large structures, very sensitive, and can give some distributed information of structures[1]. Especially, large structures are necessary to monitor the distributed temperature not only to compensate the temperature effects on the strain measurement but also to evaluate the structural integrity. Many researchers have been researched on the development of fiber optic distributed sensors. In 1976 Barnoski and Jensen reported a method to measure the loss of light nondestructively by an analysis of Rayleigh back scattering in time domain

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[2]. Sensor utilizing stimulated Brillouin scattering has the capability of measuring the absolute physical properties such as strain and temperature. Stimulated Brillouin scattering fiber optic sensor employs a pumping pulse and a CW probe beam running along a single mode optical fiber in opposite direction and detects the stimulated Brillouin back scattering signal amplified by two light beam and acoustic wave mixing [3,4]. In this method the frequency of CW probe beam differs from the pump beam by the amount of Brillouin frequency of optical fiber to enable the amplification and high intensity Brillouin scattering signal can be obtained [5]. The BOTDA sensor system equipped with one electro-optic modulator has been studied for measuring distributed strain and temperature [3].

In this study we investigated the feasibility of the continuous measurement of the distributed temperature on a building. The fiber optic BOTDA sensor system was developed with one laser diode and two electro-optic modulators. The optical fiber of 1400 m was installed on the surfaces of the building. The surface temperature was measured continuously on the time interval of 1 hour.

OPERATING PRINCIPLE

When the pulsed pumping light, which propagates along the single-mode optical fiber, is traveled and meet the continuous wave probe light, the back scattering light is amplified at the condition of Brillouing frequency as shown in Fig. 1 and Fig. 2. If the temperature acting on the optical fiber is to be changed, then the Brillouin frequency of an optical fiber is to be also changed. After knowing the Brillouin frequency, the temperature can easily be determined by this equation (1).

$$\nu_{s}(T) = \nu_{s}(0)(1 + C_{T}T) \tag{1}$$

where T is temperature and CT is the coefficient of temperature, which is known to be 1 MHz/°C for conventional single mode optical fibers used at the 1.5 μm wavelength range of the optical communication.

Based on the above discussions we calculated a simulation of a strain effect as shown in Fig. 2, which is drawn by the use of W = 30 nsec, $P_p(0)$ =1341 mW, $P_{cw}(L)$ =5.7 mW, and L=40 km into Eq. (3). In this figure, the temperature effect is assumed to induce constant values along two sections of the fiber as shown in Fig. 2. Then, according to the Eq. (1) Brillouin frequency is shifted. The temperature effect is shown as a stepwise change of Brillouin frequency in this figure so that both the location and quantities of the temperature can be determined clearly.

SENSOR SETUP AND FIBER INSTALLATION

The experimental setup for the pretest using the fiber optic BOTDA sensor is shown in Fig. 3. The system consists of an optical source assembly, two modulators, and the detector part. Optical source is composed of a DFB diode laser of its maximum output of 30 mW and normal bandwidth of 3 MHz, and an optical amplifier of its maximum output of 18 dBm. Pump pulse is generated at the electro-optic modulator 1 (EOM1, 2.5 Gb/sec modulation), which is driven by a pulse generator. Pump pulses of width, 20 ns, have been used in this experiment, which is corresponding the spatial resolution of 2 m. CW probe light is modulated at about 10 GHz by using EOM2 (20 Gb/sec) driven by a signal generator. Two 50:50 bidirectional fiber couplers were used as shown in Fig. 3. An optical detector was used to receive the backward Brillouin signal and its output data was transferred to PC by using high speed A/D converter. When CW pump light was launched into the fiber with no modulation and the frequency of CW probe light is swept over near the resonance, we obtained the Brillouin gain spectrum as shown in Fig. 4. From this measurement, we were able to deduce the fact that the Brillouin frequency shift of the present optical fiber is about 10.823 GHz and the bandwidth of spectrum at FWHM is about 13.4 MHz. The optical fiber was installed on the building as shown in Fig. 5. The total length of fiber was about 1400 m. The fiber status was verified by mini-OTDR as shown in Fig. 6.

TEMPERATURE MEASUREMENT

The temperature was measured by the fiber optic BOTDA sensor with the data averages of 10000 times. The frequency of the CW probe beam was modulated between 10.75 GHz to 10.87 GHz as the 1 MHz step. So, the measuring time is about 25 minutes. The temperature was measured at the time interval of 1 hour. Brillouin gain spectra, which are acquired for one day, were shown in Fig. 7. The frequency at maximum gain is correlated with the temperature by Eq. 5. In this figure, we can show the temperature changes of about 10 °C. Also, Fig. 8, Fig. 9, and Fig. 10 show the distribution of temperature on the surfaces of the building. In these figures, the temperature distributions at night were less fluctuated than that at noon. So, we can calculate the temperature differences between the reference distribution (temperature distribution at night) and the temporary distribution (temperature distribution at noon). It can be expected that the abnormal change of the temperature distribution is to be found to determine the abnormal status of the building from these difference distributions.

CONCLUSION

The temperature distribution on a building was measured by the developed fiber optic BOTDA sensor. The fiber optic BOTDA sensor system was constructed with one laser diode and two electro-optic modulators. The optical fiber of 1400 m was installed on the surfaces of the building. The surface temperature was measured continuously on the time interval of 1 hour. We hope that the differences between the night distribution and the noon distribution can give the useful information to determine the structural status of a building.

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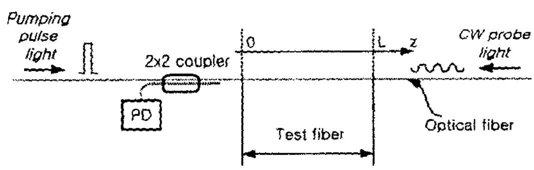


Fig. 1. Schematic diagram for the fiber optic BOTDA sensor operation.

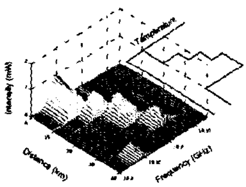


Fig. 2. Simulated signals for backward Brillouin scattering and strain effects.

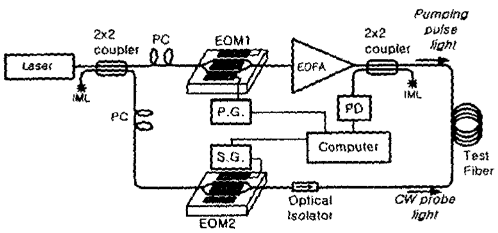


Fig. 3. A schematic diagram of the fiber optic BOTDA sensor.

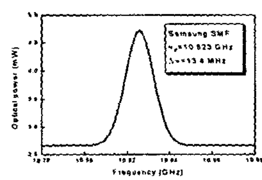
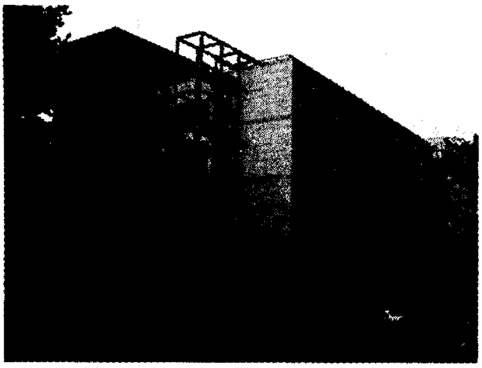
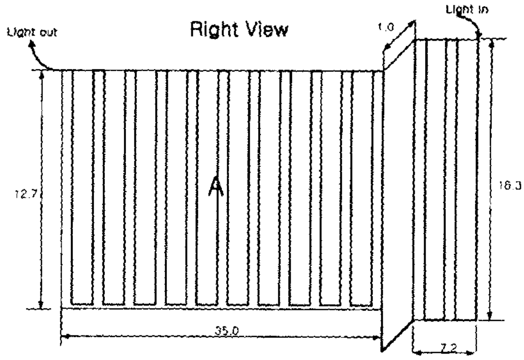


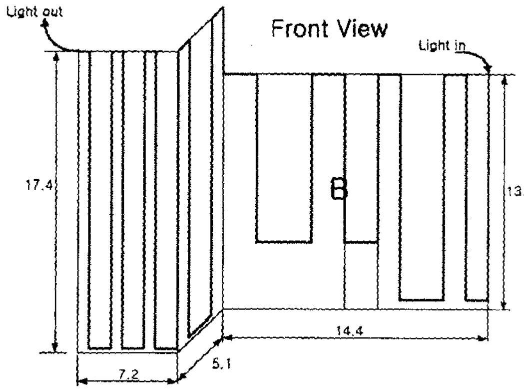
Fig. 4. Brillouin gain spectrum of the single mode optical fiber.

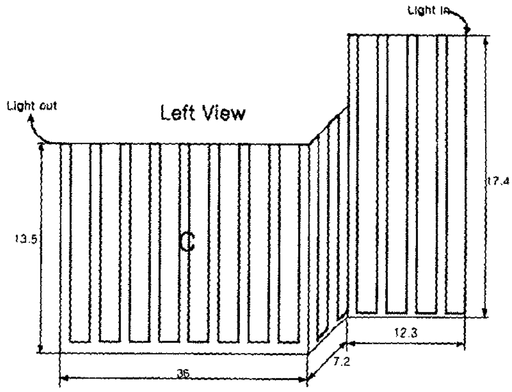


(a) Building construction installed with an optical fiber



(b) south surface





(c) west surface

(d) north surface

Fig. 5. Location of fiber installed on the building.

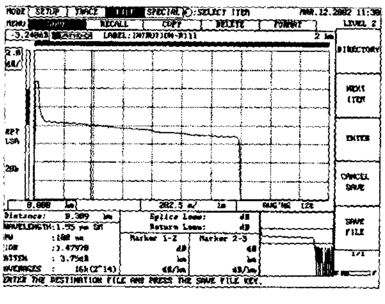
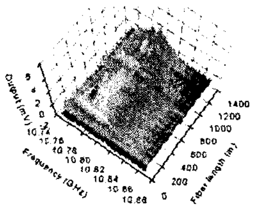
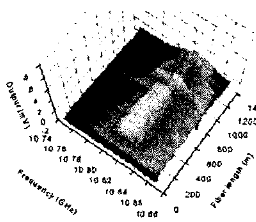


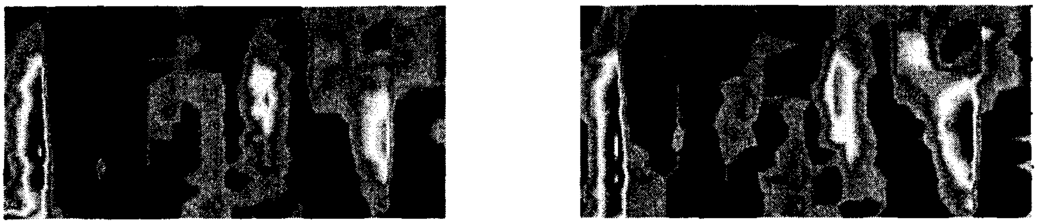
Fig. 6. Fiber status installed on the building.





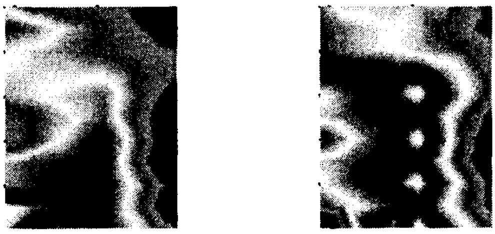
(a) At night (b) At noon

Fig. 7. Brillouin gain spectra at one day.



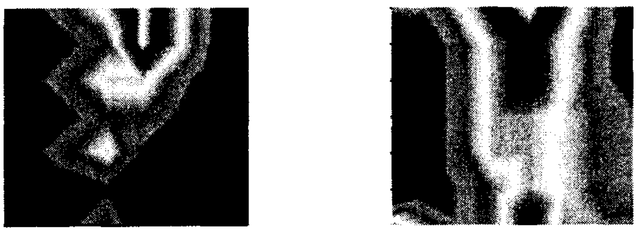
(a) At noon (Min : 18 Max : 29 Avr : 22) (b) At night (Min : 13 Max : 24 Avr : 17)

Fig. 8. Temperature distribution on south surface (A surface in Fig. 5).



(a) At noon (Min : 19 Max : 27 Avr : 23) (b) At night (Min : 15 Max : 21 Avr : 18)

Fig. 9. Temperature distribution on west surface (B surface in Fig. 5).



(a) At noon (Min : 19 Max : 25 Avr : 21) (b) At night (Min : 13 Max : 18 Avr : 15)

Fig. 10. Temperature distribution on north surface (C surface in Fig. 5).