콘크리트에 매설된 구조물 유지관리용 Fabry-Perot 광섬유 센서의 거동

Behavior of Embedded Intrinsic Fabry-Perot Optical Fiber Sensors in the Cement Concrete Structure

○김기수*, 유재욱**, 이승재***, 최롱****, 이웅종*, 김종우*
Ki-Soo Kim, Jae-Wook Yoo, Seung-Jae Lee, Long Choi, Woong-Jong Lee Jong-Woo Kim

ABSTRACTS

Intrinsic Fabry-Perot Optical fiber sensors were embedded to tensile side of the 20cm ×20cm×150cm cement concrete structures. The sensors were attached to the reinforcing steels and then, the cement concretes were applied. It took 30 days for curing the specimens. After that, the specimens were tested with 4-point bending method by universal testing machine. Strains were measured and recorded by the strain gauges embedded near optical fiber sensors. Output data of fiber sensor showed good linearity to the strain data from the strain gauges up 2000 microstrain. The optical fiber sensors showed good response after yielding of the structure while embedded metal film strain gauges did not show any response. We also specimens were broken down. In conclusion, the optical fiber sensors can be used as elements of health monitoring systems for cement concrete infra-structures.

1. Introduction

Civil structures play important roles in human being's life. People use civil structures for convenience and practical purposes, but in the same manner, the structures need proper maintenance with passing of time. If it is not maintained properly, it could fail to keep people's properties and their lives.

Not only by terrible change of nature such as earthquake, typhoon and flood, but civil structures reduce their own life span. It has emphasized necessity of health monitoring system that always measures degree of deterioration of civil structure, always predicts the life span of the structure and informs its repair time.

One of the examples of health monitoring systems was established in the bridges constructed with the precast segmental method at the riverside highway at Seoul, Korea. This system used the existing electric strain gauges

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* 쌍용중앙연구소 건설기술연구실
** 쌍용중앙연구소 전자세라믹연구실
*** 쌍용안전기술사업단 진단기술팀
**** 쌍용양회공업(주) 진단기술담당 이사

and accelerometers. The signal from a sensor in the health monitoring system is shown in Fig. 1. [1].

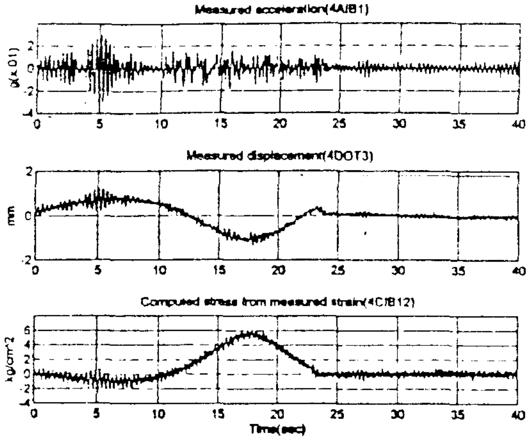

Figure 1. Measured acceleration, displacement and strain from the health monitoring system of bridge in Seoul

Potential candidates of the sensors of the system are embedded fiber optic sensors. Fig. 2 shows the monitoring system which consist of optical fiber sensors and optical components.

In this experiment, embedded intrinsic Fabry-Perot optical fiber sensors were employed. The data from the sensors showed good linearity to the data from strain gauges.

2. Embedded fiber optic sensors.

An intrinsic Fabry-Perot fiber optic sensor width circular cross-section, embedded inside either an isotropic or and anisotropic material was considered. The main components of these types of sensors are two parallel., partially reflecting mirrors spliced into the optical fiber at an L_0 distance apart.

A coherent llaser beam of light is passed along the optical fiber. The change in the reflected light intensity relates to the changes in temperature and strains of the material surrounding the sensor. The distance between the mirrors must be sufficiently small that neither the strain nor the temperature very significantly along this distance.

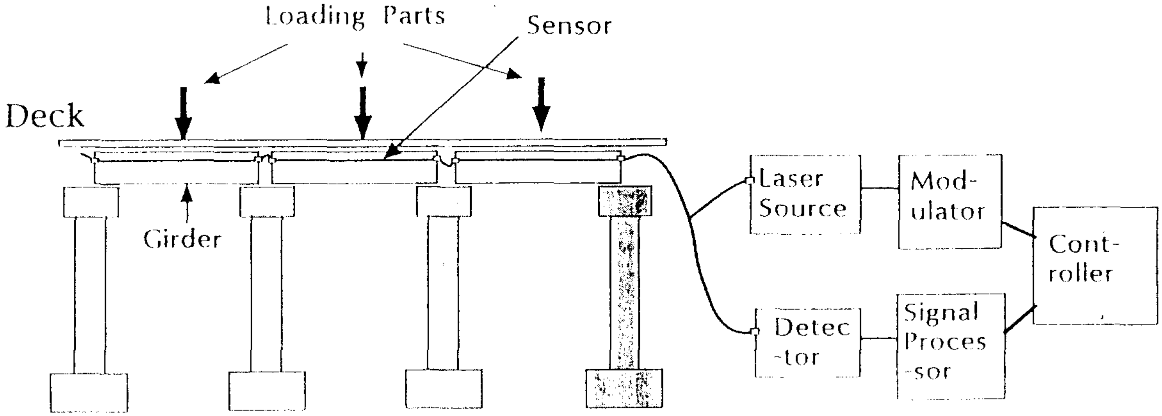

Figure 2. Health monitoring system with optical fiber sensors for a bridge

The problem is approached in three steps (Figure 3).

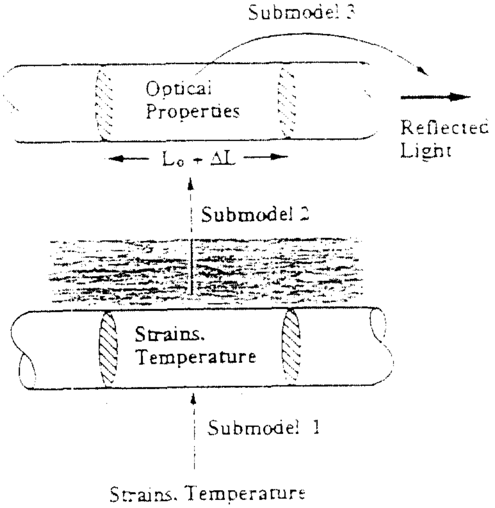

Figure 3. Illustration of the three submodel

1. The temperature and the strains in the material relate to the temperature and the strains inside the sensor (Submodel 1).
2. The temperature and the strains in the sensor relate to the change in length $\triangle L$ and to the changes in the optical properties of the sensor (Submodel 2).
3. The changes in the length and in the optical properties of the sensor relate to the changes in the intensity of the reflected light (Submodel 3).

A model which a) considers shear effects inside the sensor, b) considers both strain and temperature effects c) places no restrictions on the applied loads was developed by K. Kim, et'al [2].

In case of the embedded sensor in isotropic materials, the intensity of optical output signal(I^R) is represented by simple equation as follow[2].

$$I^R = I^o[R_a+R_b+2\sqrt{R_aR_b}\cos(K_1+K_2e_1+K_3e_h+K_4\Delta T)\cos(K_se_s)]$$

I^o is intensity of the incident light upon sensor and R_a and R_b are reflectivities of the two mirrors of the Fabry-Perot sensor.

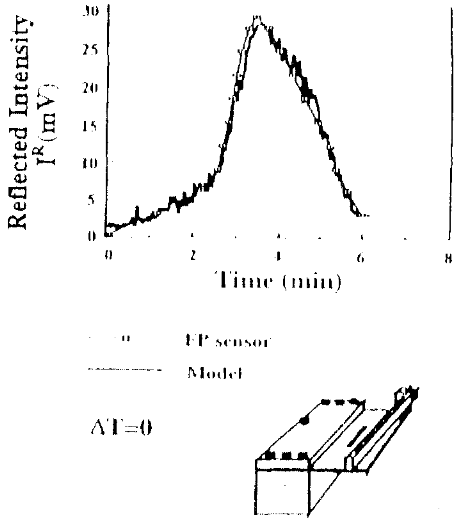

Figure 4. The measured and calculated insenties of reflected light

K_1, K_2, K_3, K_4 and K_5 are the constants composed of elastic moduli and photoelastic constants and e_1 is the strain toward optical fiber. e_2 and e_3 is the hydrostatic strain and the shear strain toward cross section of the optical fiber. $\triangle T$ is the temperature change.

Fig. 4 shows that strains and output light intensities calculated from data of strain gauge and measured through the optical fiber sensor embedded inside a composite.

3. Experimental Procedure

LG single mode silica fiber for 1.5μm wave length light was used in the experiments. The partially reflecting mirrors inside the fiber were produced by splicing the TiO_2-coated fiber to a bare fiber with fusion splicer. The thickness of TiO_2 before splicing was about 1000 Å.

The mirror fabrication method is very similar to that of C.E. Lee et'al[3]. The cavity lengths (L_o) between two mirrors are about 1cm. The sensors were embedded in 20cm×20cm×150cm cement concrete specimens.

We attached an intrinsic Fabry-Perot sensor on a reinforcing steel with adhesive and strain gauges on the other reinforcing steel near the Fabry-Perot sensor for comparison. and then we placed the reinforcing steels in the wood mold and poured the concrete mixture to produce specimen for loading test. After hardening one month in the air, we put this specimen on the U.T.M.(Universal Testing Machine) and carried out 4 point bending test. Data from Fabry-Perot sensor were measured with peak counting method using eye detection and with X-Y plotter.

4. Experimental Results

Data were obtained from the two types of tests. First, the sensors were embedded to the specimens which failed by the bending force. The specimens had several ribs crossing to the main reinforcing steels which prevented shear failure. We obtained data from the sensors and strain gauges. They showed good linearity as shown in Fig. 5

Second, the specimens had only two main reinforcing steels without any ribs. Therefore the specimens were failed by the shear force. The sensors were attached to the reinforcing steels.

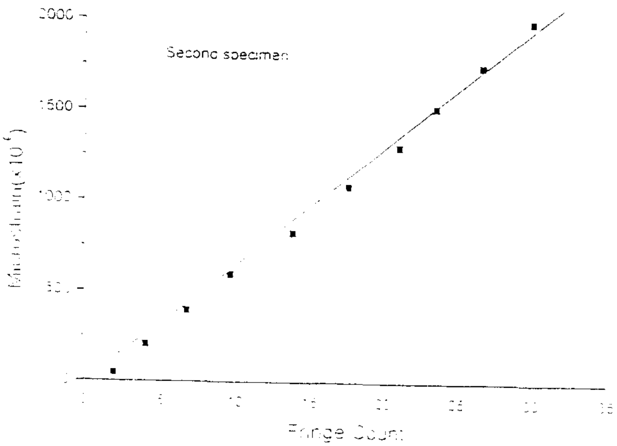

Figure 5. Correlation between optical fiber sensor and strain gauge data

We obtained data from the sensors as shown in Fig. 6 The data from optical fiber sensors were recorded by X-Y plotter. Figure 6. shows small fluctuations due to the crack propagation and the amplitude change according to increasing load. The phenomenon occurs due to shear strain in the cross-sectional plane of the sensor. It was predicted by K.Kim, et'al shown in Fig. 7 [2].

The sensor showed good response even after failure.

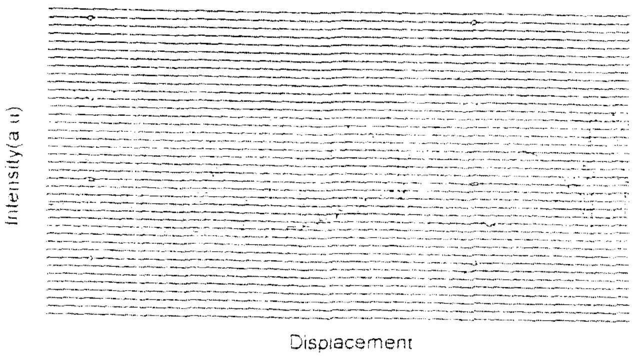

Figure 6. The data from the Fabry-Perot sensor recorded by X-Y plotter

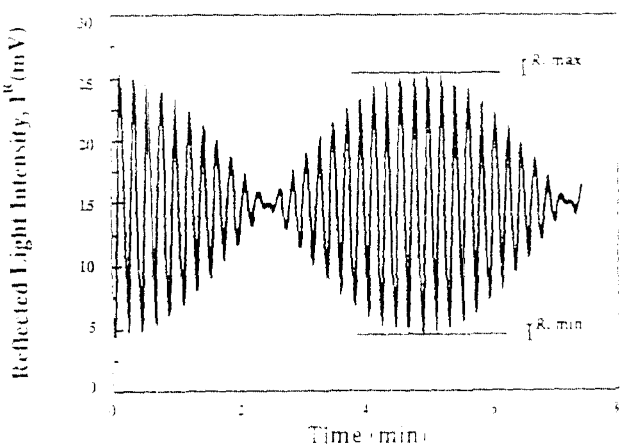

Figure 7. Typical variation of the reflected light Intensity of a Fabry-Perot sensor with time for a load applied at a uniform rate

5. conclusion

Output from the Fabry-Perot sensor showed good linearity to output from the strain gauge. From this, We can apply Fabry-Perot sensors to maintenance and control system instead of strain gauges. Considering that the optical fiber sensors gave advantages of high speed response, good durability, no production noise from electromagnetic waves, it is possible to construct very stable maintenance and control system.

References

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