The Progress of Smart Materials/Structures in Korea

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ABSTRACT

This paper summarizes the experience of Korea in various subdisciplines of smart materials and structures technology. Fiber optics and its applications have been studied by physics department at KAIST and optical fiber communications and signal processing by electrical engineering department. Smart material/structural system, as interdisciplinary discipline, is somewhat in its infancy and recently brought some attention to mechanical and aerospace engineering department in Korea. Some results which are currently under investigation at KAIST are presented.

INTRODUCTION

Technology of smart materials and structures is highly interdisciplinary in its nature. Smart materials and structural systems may be constructed by one or the combination of optical fiber sensor, piezoelectric film, shape memory alloy, and electro-rheological fluid. Fiber optics have been studied by scientists of physics department and optical fiber is manufactured mainly for communication in Korea. Shape memory alloy was the subject of material scientists and recently basic research on shape memory alloy has begun to apply as a shape controller of smart structural system. Composite materials have become more accepted in the engineering environment. Optical fiber sensors are one of the promising sensor technology for applications in smart materials and structures. One of the advantages for optical fiber sensors is easy to embed within the materials such as composite structures to provide in-situ measurements of composite cure as well as health monitoring during service. Some of research areas on smart material/structure systems under investigation in Korea are as follows:

- Optical fiber sensor :

Department of Aerospace Engineering, Department Mechanical Engineering, Department of Physics at Korea Advanced Institute of Science and Technology (KAIST), Korean Air, Ssangyong Co.

- Piezoelectric ceramic/film :

Department of Mechanical and/or Aerospace Engineering, Inha University, KAIST, Pohang University of Science and Technology(POSTEC), Seoul National University

- Shape Memory Alloy :

Department of Mechanical and/or Aerospace Engineering, Inha University, KAIST, Pohang University of Science and Technology(POSTEC)

- Electro-rheological fluid :
  Department of Mechanical Engineering, Inha University

Optical fiber sensor

The progress of the performed research on the fiber optics at KAIST is as follows;

- Quasi-Static load
  - Michelson interferometer
  - extrinsic Fabry-Perot interferometer(EFPI)
- Dynamic load

- the 3x3 passive demodulated fiber Michelson interferometer
- phase shifted EFPI by the two probe

- Data Process
- Failure Detection

- simultaneous sensing of the strain and failure
- detection of matrix cracking
- low velocity impact characteristic

- Real-Time Monitoring

As the basic research applying the optical fiber sensor(FOS) to composite structures, strain measurement was conducted. The used FOS were Michelson interferometer and EFPI. The fiber optic Michelson interferometer and EFPI were embedded in the graphite/epoxy laminates. Under the quasi-static loading, strains measured by Michelson sensor and EFPI showed good agreement with those by the electrical strain gage(ESG). The signals of EFPI sensor were compared with those of Michelson interferometer. For the EFPI sensor, the method to distinguish the loading directions using the envelope of the interferometric fringe in the quasi-static state was proposed. Since the fiber optic interferometric sensor have the 2π ambiguity, it is necessary more information to decide the loading direction. Researches which use the 3x3 passive demodulated Michelson sensor and the phase-shifted EFPI having the two probe were performed to overcome this limitation. The result of Michelson sensor applied the passive demodulated technique is shown in Fig. 1. Also, the research by the phase-shifted EFPI adopting the same method was performed. Figure 2 is the phase-shifted EFPI manufactured in the laboratory. The experimental results are shown in Fig. 3. In the fiber optics, signal process is very important to apply FOS to the real structure. Using the proper filter set, strain and failure instants in composite beam were simultaneously sensed as shown in Fig. 4. In the case of the Michelson sensor, demodulation is difficult since the beating and drifting of signal were caused by the change of polarization axis in the sensing part. The method was suggested to overcome this disadvantages through the adaptively track of the moving mean value of the intensity envelope. This method shows the good capability of the data processing in the Michelson sensor. In the passive demodulation technique, arc-tangent method and phase-unwrapping technique were used.

The most frequently encountered first ply failure mode in laminated composites is the matrix crack. Matrix cracks can be detrimental to the structural reliability and durability of laminated composites. Recently, researches on the fiber optic sensors which are used to detect matrix cracking are on the progress. An optical fiber sensor based on the Michelson interferometer was constructed to detect AE(acoustic emission) signal occurred by matrix cracking in the laminated composites. In the experiment, the frequency of the detected signal was compared to the excitation frequencies with the frequency range of AE by matrix crack. The survivability of optical fiber sensors was examined experimentally. The experiment showed that it was advantageous to embed an optical fiber in the direction of the reinforced fiber of the composite laminates to protect the optical fiber from matrix cracks of various types.

Also, the effects of the embedded direction of the optical fiber was investigated. The matrix cracking under tensile loading was detected by the obtained AE signal for cross-ply laminated composites, and it was confirmed by the replica method. Figure 5 shows the experimental AE signal detected by the optical fiber sensor and power spectrum of the original signal. In the frequency analysis of AE signal for matrix cracking, the characteristic of frequency have the range of frequency approximately up to 120 kHz.

Low-velocity impact is one of important issues in composite structures. The mechanical behavior of composite panel embedded FOS was investigated. The embedding location of FOS was decided using the finite element analysis. Also, the sensitivity of FOS under the low-velocity impact loading and the connecting problem between the composite panel and FOS system were discussed. When low-velocity impact was applied to composite panel, Figure 6 shows the result which represent the surface strain measured by ESG and the intralaminar strain measured by FOS.

Great attention has been paid to the fiber optic sensor as the monitoring of structural health becomes important in recent year. The structural strains due to external loading have to be measured to monitor the structural health. For this purpose, the real-time system that can sense deformation of structures without delay is needed. The real-time strain measurement system was constructed with a 3x3 passive fiber optic Michelson interferometric sensor and a signal processing program user-friendly written in Visual Basic. The signal processing program real-timely converted the signal of FOS to the strain. For assuring the operation of the signal processing program, it was performed the off-line simulation that compared strain by FOS with that by ESG subject to the tensile loading/unloading. The specimen was repeatedly subjected to sinusoidal cyclic tension-tension load. Figure 7 shows the result measured by the real-time monitoring strain measurement system using FOS subject to the dynamic load. Since the real-time strain measurement system could successfully detect the structural dynamic strain, it can be used to measure the strain of structure subject to general loads in real situations.

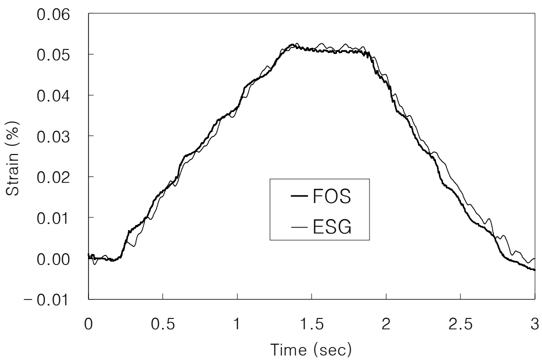


Fig. 1 Result of the 3x3 passive demodulated Michelson interferometer

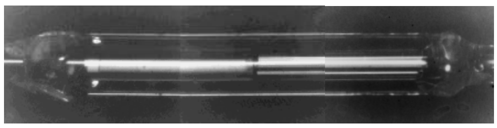
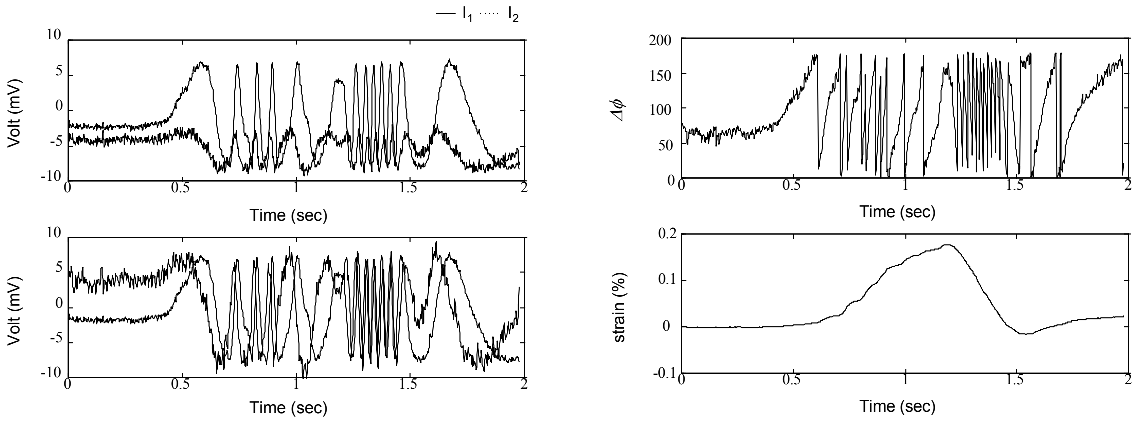


Fig. 2 Photography of the phase-shifted EFPI



(a) Intensity vs. Time curve

(b) Phase and Strain

Fig. 3 Results of the phase-shifted EFPI

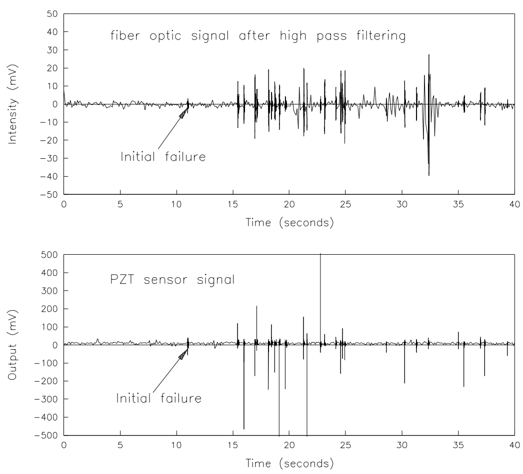


Fig.4 Simultaneous detection of strain and failure signal

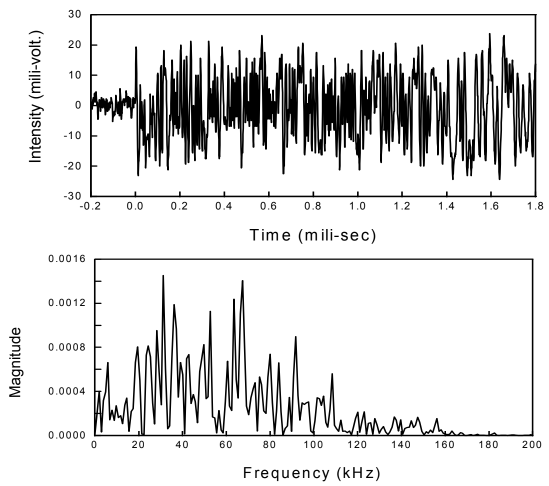


Fig. 5 AE signal and power spectrum detected by FOS when the matrix cracking occurs

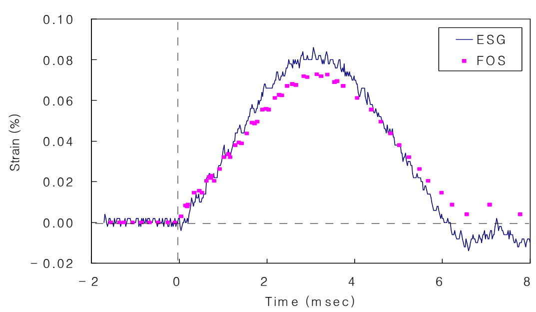


Fig. 6 Transient response of FOS and ESG subject to the low-velocity impact load

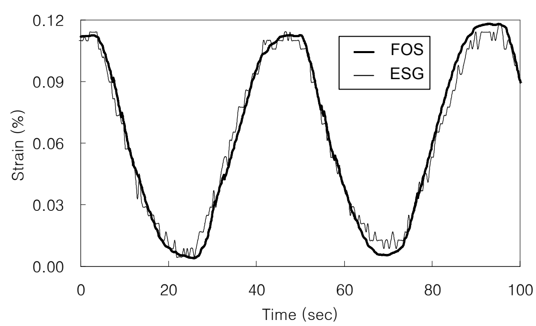


Fig. 7 Real-time monitoring of the structural strain subject to the dynamic load

Piezoelectric ceramic/film

- Finite Element Analysis of Smart Composite Structures Using Piezoelectric Sensors and Actuators
- Optimal Placement of Piezoelectric Actuators in Smart Structures Using Genetic Algorithms
- Development of Effective Vibration Control Algorithms
- Experimental Study for Vibration Control of Composite Structures Using Piezoelectric Sensors and Actuators

In the near future, smart structure technologies will be widely used in aerospace, defense, and civil industries. Among several features of smart structures the capabilities of active vibration control are main interest in this laboratory. In order to analyze the dynamic and controlled behaviors, finite element analyses have been performed. The analyses are based on linear piezoelectricity equations and several plate theories. As a design purpose, an optimization of piezo-actuator distributions using Genetic algorithms has been studied. Several control algorithms have been used to control the vibrations including classical methods, optimal control, IMSC(Independent Modal Space Control), and PPF(Positive Position Feedback). Recently adaptive algorithms such as NN(Neural Network) and Fuzzy have been adopted to nonlinear and time-varying structures. Finally digital vibration control system for composite structures are constructed and tested. The active vibration control experiments have been performed.

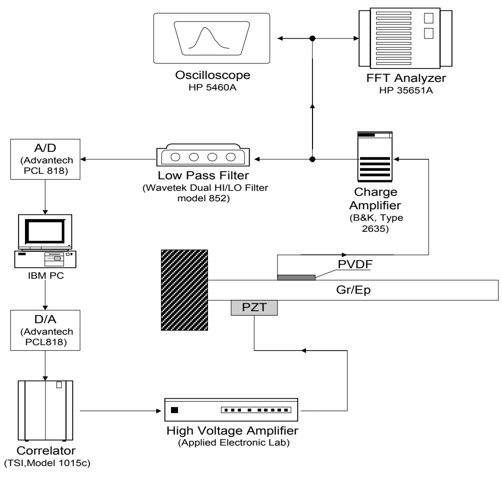


Fig. 8 Over-all experimental setup.

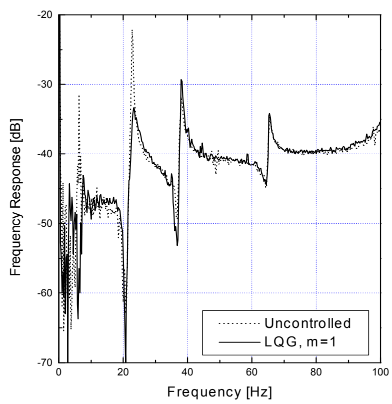


Fig. 9 Simultaneous Control of the first two modes.