FIBER BRAGG GRATING SENSOR SYSTEM FOR MONITORING COMPOSITE AEROSPACE STRUCTURES

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ABSTRACT

To investigate strain-sensitive characteristics of fiber Bragg grating (FBG) sensors, a minimal sensing system consisting of multiplex FBG sensors and signal demodulating and processing instruments was constructed. FBG sensors were designed with different package structures for respectively sensing strain or temperature parameters, and they returned measurand-dependent wavelengths back to the interrogation system for measurement with high resolution. In this paper, tests were performed on structure samples with step-wise increase of deformations. Both FBG sensing system and strain gages were tested and compared. Experimental work proved that the FBG sensing system had a good level of accuracy in measuring the static response of the tested composite structure. Moreover the additional advantages such as damp proofing, high sampling rates and real-time inspection make the novel system especially appropriate for load monitoring and damage detection of aerospace structures.

INTRODUCTION

Aerospace structure monitoring is critical for the successful operation of space missions. Recently structural health monitoring (SHM) systems have been generally investigated and developed to monitor the structural integrity and assess the state or condition of aerospace systems[1-5]. Based on health assessment data gathered by SHM systems, appropriate decisions / recommendations could be made during storage, handling, transportation, pre-launch, mission, maintenance and turnaround operations.

SHM systems could use in parallel various sensing technologies specifically appropriated to the conditions to monitor, and different sensor types and locations may be highly distributed. The primary requirements for the sensors used are[6-7]:

- sufficiently small and lightweight,

- having no adverse impaction on the system performances,
- having minimal impaction on the system costs,
- withstanding severe environmental conditions,
- long lifetime or easy maintenance.

Currently we have on the market a wide range of sensing technologies suitable for SHM applications, including fiber-optic sensors, active and passive acoustic sensors, electromagnetic sensors, wireless sensors, MEMS and nanosensors. For aerospace applications, fiber-optic sensors are one of the leading candidates and have received considerable attention.

FIBER-OPTIC SENSORS

Fiber-optic sensors provide numerous advantages for aerospace applications. These include[8-16]:

- insensitivity to electromagnetic interference,
- freedom from sparking electrostatic discharge,
- lightweight and flexible harness,
- multiplexing and multi-parameter sensing,
- high measurement accuracy,
- low power requirements per sensor,
- remote interrogation and operation,
- potential to embed in composite structures.

There are many potential applications for fiber-optic sensors on aerospace vehicles, ranging from the mapping of strain and temperature distribution to monitoring the propellant leakage.

Fiber Bragg grating (FBG) sensors represent a promising solution for structural monitoring as they are suitable for multi-parameter sensing, can be multiplexed efficiently and can either be embedded or surface mounted. The application of strain on a fiber Bragg grating causes a relative elongation of its grating period, leading to a direct proportional relative shift $\Delta\lambda_B$ of the reflected Bragg wavelength λ_B[17].

Calculation of strain ε is performed from the measured relative shift of its Bragg wavelength $\Delta\lambda_B/\lambda_B$, with $\Delta\lambda_B = \lambda_B - \lambda_{B0}$:

$$\varepsilon = \Delta\lambda_B / \{(1-p)\,\lambda_{B0}\} \qquad (1)$$

p – photo-elastic coefficient of fiber core material, p = 0.23;
λ_{B0} – Bragg wavelength λ_B at start time t = 0 of measurement with an assumed strain ε (t=0) = $\varepsilon 0$, e.g., $\varepsilon 0 = 0$.

Note that temperature cross-talk on strain readings could be numerically compensated from the measuring results of separate FBG temperature sensors.

EXPERIMENTS AND DISCUSSIONS

Figure 1 shows a sketch of the minimal sensing system consisting of multiplex FBG sensors and signal demodulating and processing instruments. FBG sensors were designed with different package structures for respectively sensing strain or temperature parameters, and they could either be embedded or surface mounted in the test structure. With the structural deformations, FBG sensors returned measurand-dependent Bragg wavelengths back to the demodulator through optical fibers. The demodulator read out the relative shift of the Bragg wavelength and communicated with the signal processing unit, where the strain were calculated and displayed.

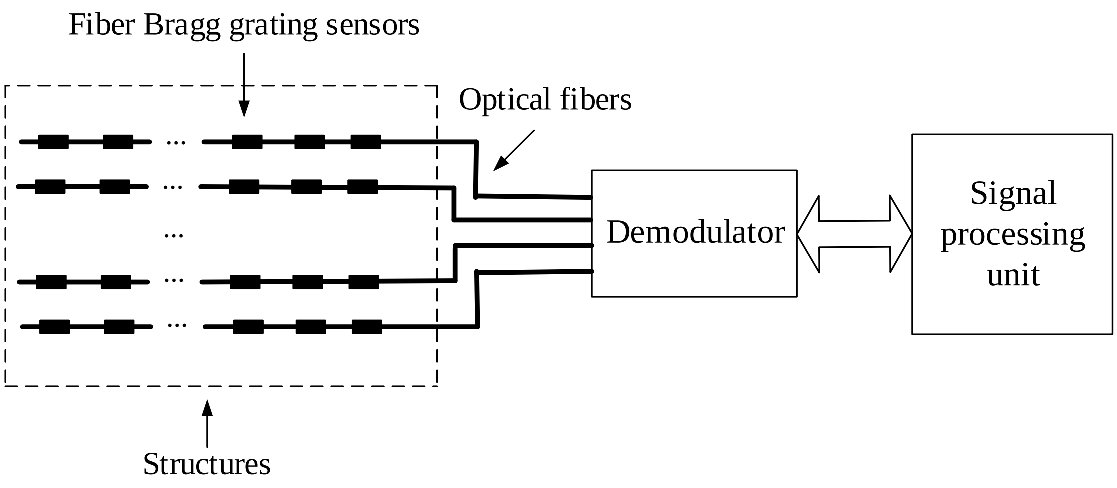

Figure 1. Sketch of the minimal sensing system

Tests were performed at room temperature on composite structure samples with FBG strain sensors mounted on the surface. For the compensation of temperature cross talk, a second FBG is positioned very close to the strain sensor and measures the temperature without any mechanical coupling to the structure. Structural deformations were induced stepwise by an external force and the strain was read out by the sensing system. Foil gages were bonded at corresponding positions for comparison.

Figure 2 demonstrates a comparison of the FBG sensing system to the foil gage system in the structural strain measurement. The FBG sensing system performed very well with linear correlation with the commercial strain transducer in the measurement range from 0με up to about 7000με.

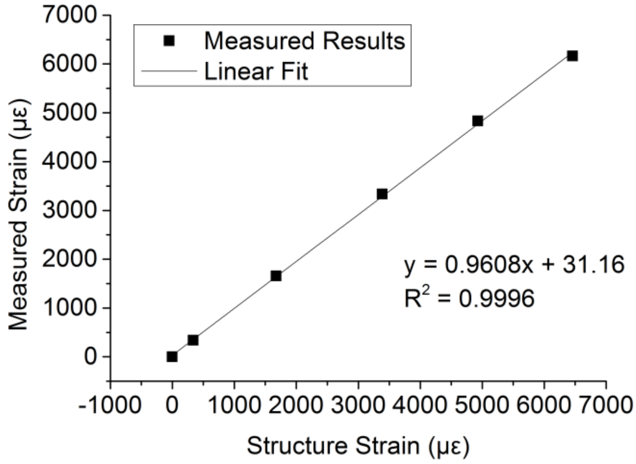

Figure 2. Measurement results of the FBG sensing system

During these measurements, no obvious hysteresis was obtained. It means that the applied gluing process for the FBG sensors is well-suited for structural strain measurement in an extremely wide range. Moreover the FBG sensing system has shown additional advantages such as damp proofing, high sampling rates and real-time inspection, making it especially appropriate for load monitoring and damage detection of aerospace structures.

CONCLUSIONS

Experimental work proved that the presented FBG sensing system is suitable for monitoring composite aerospace structures. FBG strain sensors mounted on the structural surface are capable of measuring strain in a wide range from 0με to about 7000με with good accuracy. For the compensation of temperature cross talk, a special FBG temperature sensor has been designed. The FBG sensing system developed in this research and to be further optimized will enable spacecrafts to reach new performance, reliability, and safety levels.

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