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Viability of using an embedded FBG sensor in a composite structure for dynamic strain measurement

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Abstract

In this paper, the utilisation of an embedded fibre-optic Bragg grating (FBG) sensor to measure dynamic strain of a clamped-clamped glass fibre composite beam is presented. A dynamic calibration test for strain measurement of the composite beam by the embedded FBG sensor and surface mounted strain gauge, at different vibration frequencies was conducted. Experimental results shown that the relationship between the photovoltage and strain measured by the embedded FBG sensor and strain gauge, respectively exhibited a linear fashion, when the strain value exceeded 1 με. Below this strain limit, the strain gauge could not precisely respond to the true strain of the beam. However, the signal extracted from the FBG sensor could truly reflect the strain of the beam at high vibration frequency condition. The first-two natural frequencies can be sharply indicated by a captured spectrum measured from the FBG sensor. Due to the out-of-plane vibration amplitude decreases with increasing the vibration frequency, the second natural frequency could not be clearly measured by the results extracted from the strain gauge.

Keywords: Fibre-optic sensor; Smart structures; Measurement

1. Introduction

In the past decade, advanced composite materials have been widely used in a variety of load-bearing structures such as rotor blades, aircraft fuselage and wing structures. These structures are always subjected to unexpected external excitations at varied vibration frequency ranges. These dynamic interferences may cause the structures suffering from fatigue damages and/or catastrophic failures due to the excitation frequency approaches to the natural frequency of the structures. Therefore, development of smart composite structures that comprises of integrated sensors, actuators and micro-processor(s) becomes a great challenge in this century. Fibre-optic Bragg grating (FBG) strain and temperature sensors have been broadly accepted as intrinsic structural health monitoring devices for measuring strains (mechanical and thermal), corrosion and vibration characteristics of smart composite structures [1–3]. The advantages of using the FBG sensors as embedded sensing devices of the

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composite structures include their small physical size, immunity of electromagnetic interference, light-weight, relative signal stability and suitability for wavelength multiplexing. Lau et al. [4] has proved that no significant mechanical degradation occurred when optical fibres were embedded into composite structures.

The principle of FBG technology is to measure the reflective signal that depends on the changes of spatial period and core refractive index in a grating region, of an optical fibre when it is subjected to elongations. If a FBG sensor is embedded into a composite structure, any change of the strain in the structure represent that the embedded fibre would be subjected to the same quantity of strains. Measuring the strains of the fibre results in reflecting the strains of the structures if a perfect bond between the fibre and composite is assumed [5].

For static strain measurement, Kang et al. [6] constructed a FBG sensor system to real-timely monitor the strains of a filament wound composite tank. Lau et al. [7,8] also presented experimental studies on strain measurements using embedded FBG sensors in composite, concrete and composite-strengthened concrete structures. They found that the embedded FBG sensors could measure the true strain of the structures compared with externally bonded strain gauges, particularly at a region close to a crack tip or faces. James et al. [9] studied the transient response of gun barrel by using FBG sensors. They revealed that the accurate strain measurement could be maintained at any harsh mechanical and electromagnetic environments. One of our authors [10] also found that the FBG sensor technology could be used to measure the vibration characteristics of air flow. Davis et al. [11] measured the vibration mode shapes and identified the natural frequencies of composite beams using surface attached FBG sensors. However, only little attentions have been paid on dynamic strain measurements that truly respond to the mechanical performance of structures, on the use of the embedded FBG sensors.

This paper aims to experimentally study the feasibility of using an embedded FBG sensor, as a dynamic strain measuring device for a clamped-clamped composite beam subjected to an external excitation at different vibration frequency ranges. The principle of dynamic strain measurements with FBG sensor is discussed. A comparison of the results extracted from the FBG sensor and an externally bonded strain gauge is given.

1.1. Principle of dynamic strain measurement with FBG sensor

The principle of FBG strain sensor is to measure the change of reflected signal from a grating when it is subjected to elongation. This change would influence the reflective index (n_b) and spatial pitch Λ at the core section of this sensor [8]. According to the Bragg's law, the Bragg wavelength (λ_B) that is reflected from the sensor is given by

$$\lambda_B = 2n_b\Lambda \tag{1}$$

By neglecting the temperature effect of the sensor, the relationship between the reflective Bragg wavelength shift ($\Delta\lambda_B$) corresponding to the change of strain at the grating region ($\Delta\varepsilon_g$) can be expressed as

$$\Delta\lambda_B = K\Delta\varepsilon_g \tag{2}$$

where K is the theoretical gauge constant. In the static strain measurement, the constant "K" can be measured by conducting a traditional tensile test. A schematic illustration of a FBG strain measuring system is shown in Fig. 1. Light is emitted from a superluminescent light emitting diodes (SLED) system to a coupler which acts as a Y-type channel to guide the emissive light to the FBG sensor and the reflective signal back to an optical tuneable filter (OTF). Photodetector and signal analyser are then used to detect the power output of the reflected light and convert the final signal into voltage quantity in real time, respectively. Owing to the dependence of the photodetector output denoted by photovoltage-variation (ΔV_{photo}) and the wavelength shift ($\Delta\lambda_B$) when the signal passes through the OTF

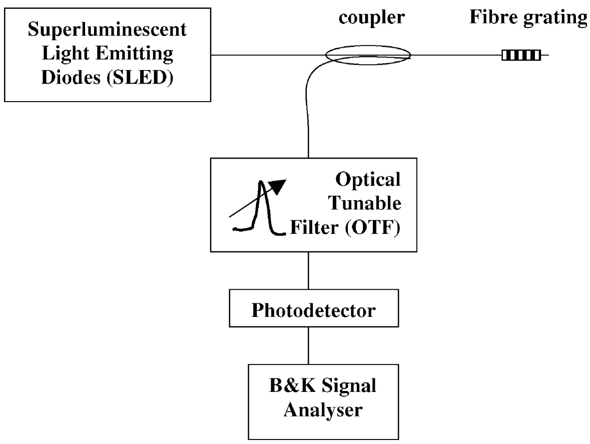

Fig. 1. FBG strain measuring system.