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Damage identification in a holed CFRP laminate using a chirped fiber Bragg grating sensor

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Abstract

This study proposes damage identification for holed CFRP cross-ply laminates using an embedded chirped fiber Bragg grating (FBG) sensor. We investigated changes in the reflection spectrum of the chirped FBG sensor due to damage near the hole. The reflection spectrum of the chirped FBG sensor was further studied by estimating the strain distribution along the gage section as an inverse problem based on the spectrum shape. We experimentally confirmed that the reflection spectrum of the chirped FBG sensor changed distinctively within certain wavelengths when each type of damage (transverse cracks or delamination) occurred and extended. Local strain changes were estimated from the reflection spectrum of the chirped FBG senso; their locations coincided with those for the observed transverse cracks. We also demonstrate damage identification for the holed specimen and conclude that this feature of the chirped FBG sensor provides successful identification of a damage pattern near the hole.

Keywords: A. Smart materials; FBG sensor; C. Finite element analysis (FEA); C. Stress concentrations; D. Non-destructive testing

1. Introduction

Advanced composite materials, such as CFRP, are frequently applied to primary load-bearing structures in various industries because of their good specific stiffness and strength. These structures may include stress concentrations, such as pin-loaded holes. These stress concentrations induce a complicated damage process that concurrently includes splits, transverse cracks, and delamination [1]. Detecting and monitoring the damage process near stress concentrations is essential to ensure the safety of the composite structures.

Structural health monitoring techniques have recently been developed for these composite structures [2,3]. Fiber Bragg grating (FBG) sensors have suitable characteristics for health monitoring, such as accurate strain and/or temperature measurements and multiplexing capability [4–6]. Strain monitoring is performed in conventional health monitoring applications by measuring the wavelength shift of the light reflected from the FBG sensor following injection of the broadband light [7]. FBG sensors are also sensitive to non-uniform strain distributions; these effects appear in the shape of the reflection spectrum [8–10]. Takeda and his colleagues [11,12] first applied this feature to detect transverse cracks or delamination in CFRP cross-ply laminates. The authors [13] demonstrated that the reflection spectrum of an embedded FBG sensor is useful for monitoring the damage process in notched CFRP cross-ply laminates.

The refractive index of the core in an optical fiber periodically changes along the gage section of an FBG sensor; this index change is known as grating. The wavelength of reflection λ is specified by the grating period Λ as $\lambda = 2n\Lambda$ (n: effective refractive index) [4,5]. The reflection spectrum for a conventional FBG sensor with a uniform

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distribution in the grating period (referred to as a uniform FBG sensor) exhibits a single narrow peak, as depicted in Fig. 1(a). A chirped FBG sensor is a special FBG sensor with a monotonic distribution in the grating period, as illustrated in Fig. 1(b). The reflection spectrum for a chirped FBG sensor is therefore broader than that of a uniform FBG sensor. Moreover, the wavelength of the reflection spectrum for a chirped FBG sensor has a one-to-one correspondence to the position along the gage section, which is an advantage of a chirped FBG sensor over a uniform FBG sensor. Okabe et al. [14] used chirped FBG sensors to detect and locate transverse cracks in CFRP cross-ply laminates. The authors [15] also applied chirped FBG sensors to monitor the damage process in holed CFRP cross-ply laminates and demonstrated that each type of damage (transverse cracks or delamination) could be simply located by the wavelength in the reflection spectrum measured under completely unloaded conditions.

The purpose of this study is to identify the damage pattern in holed CFRP cross-ply laminates based on the reflection spectrum of the embedded chirped FBG sensor. The authors [16] successfully identified the damage pattern in a notched laminate as an inverse problem, based on the reflection spectrum of a uniform FBG sensor measured under loaded conditions. This study proposes damage identification under completely unloaded conditions, which is possible with periodic inspections of the composite structures. Moreover, it is expected that a chirped FBG sensor can improve the estimation of the damage pattern compared to that by a uniform FBG sensor because of the position information along the gage section.

This paper is organized as follows. Section 2 describes tensile tests for holed CFRP cross-ply laminates with an embedded uniform FBG sensor and an embedded chirped FBG sensor. The changes in the reflection spectrum for these FBG sensors due to damage near the hole are investigated experimentally. Section 3 introduces the estimation of the strain distribution along the gage section based on the reflection spectrum of the chirped FBG sensor and discusses the linkage between the damage location and the spectrum shape. Finally, Sections 4 and 5 demonstrate damage identification based on the reflection spectrum of the chirped FBG sensor measured under completely unloaded conditions and compares the results with those by a uniform FBG sensor.

2. Experiment

2.1. Materials and measurements

We used CFRP cross-ply laminates (T800H/3631, Tray Industries, Inc.) with a stacking configuration of $[0_2/90_2]_s$ in

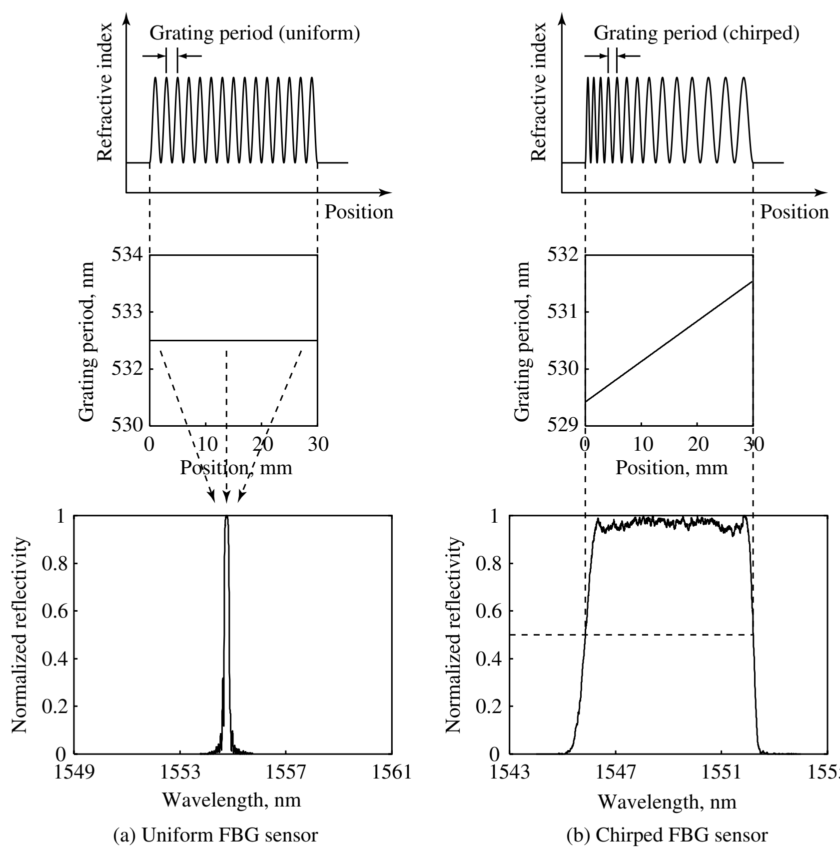

Fig. 1. Grating period distributions and the corresponding reflection spectra for two types of FBG sensor.