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ScienceDirect

Procedia Structural Integrity 5 (2017) 729–736

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Structural health monitoring on an unmanned aerial vehicle wing's beam based on fiber Bragg gratings and pattern recognition techniques

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Abstract

Composite materials have been extensively used on new aircraft airframes because of their advantages over metallic materials. This represents a difficulty for damage detection, a vital task for safety on the aerospace industry, as most nondestructive testing techniques are not effective on these materials since those usually present internal failures like delaminations which are difficult to detect. A miniaturized strain acquisition and wireless transmission system is presented alongside with a novel technique for structural behavior assessment, based on the use of Fiber Bragg Gratings to measure strains and non-supervised classification techniques to recognize different operational conditions. Operational tests were performed on an Unmanned Aerial Vehicles wing's beam, made of composite materials with the sensors embedded during its manufacturing. Strain measurements were processed using an Optimal Baseline Selection methodology. The tests performed proved the system's capability to identify and separate different operational conditions for a healthy structure, based on the analysis of its strain fields. The implementation of this methodologies can lead to perform real-time damage detection on aerospace complex structures made of composite materials.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: structural health monitoring, fiber Bragg gratings, unmanned aerial vehicles, pattern recognition techniques.

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2452-3216
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.163

1. Introduction

On the last few decades, the usage of composite materials has been growing on aerospace structures and airframes, because of their advantages like highly reduced corrosion sensitivity, enhanced fatigue behavior, and much higher specific mechanical properties in comparison with traditional metallic structures. By contrast, composites have some issues related to damage detection, an important procedure to the air transport industry, where reliability and safety are the most important matters and one of the costliest ones.

Finding and assessing damages on composite materials are complicated tasks because composite's main failure mode occurs when laminae get separated from each other. This happens inside the material and is completely hidden from the outside. Besides, most nondestructive testing methods like penetrant and magnetic testing, are not effective on this kind of materials.

As defined by Boller et al (2009), Structural Health Monitoring (SHM) comprises the usage of sensing devices on a structure, permitting to record, localize, analyze and eventually predict damage, looking to integrate nondestructive testing as an essential component of materials and structures. SHM techniques based on Optical Fiber Sensors (FOS) for strain measurement are a solution to this issue, because they allow to monitor structural behavior with a low overall cost and are easy to implement on composite airframes. Fiber Bragg Gratings (FBGs), a specific kind of FOS, can be embedded into the composite material with minimum invasion. They present advantages over traditional strain sensors as they are lightweight, rugged and immune to electromagnetic interferences, high fatigue resistance, high sensitivity, etcetera.

When several FBGs are located at different airframe's points of interest, strain values can be measured and correlated to build the strain distribution across the structure, which is known as its strain field. When the loads applied to the healthy structure are on the region where the material behaves elastically, and the structure presents no buckling, the strain field is only subjected to changes with the airframe's operational condition. If a damage is present on the material, it may cause changes in the structure's stiffness and consequently in the strain field. Having this clear, it becomes important to separate changes in the strain field caused by its operation procedures from the ones triggered by the presence of damages. This can be done by processing strain field data with pattern recognition techniques.

The development of a remote strain measurement acquisition and transmission system, based on FBGs, a Wireless Local Area Network (WLAN) and pattern recognition algorithms to detect different operational conditions on a healthy structure is presented. On this work, the main beam of an Unmanned Aerial Vehicle´s (UAV) wing was made of carbon fiber reinforced polymer (CFRP) with embedded FBGs. Different operational tests were performed on ground, acquiring strain data from the sensors and processing it with an Optimal Baseline Selection (OBS) combined with a Local Density-based Two-level Clustering (DS2L) methodology to uncouple the tested operational conditions. The effectiveness of the whole system was tested as well, executing an experiment to assess the performance of the wireless transmission system and its effect on the final acquisition rate.

2. Conceptual Frame and Overview

2.1. Fiber Bragg Gratings

FBGs are wavelength-type Fiber Optic Sensors employed to measure strain and temperature in the region of the underlying material that is near to the grating. The sensor acts as a transducer between the physical variable of interest and the light travelling through the optical fiber. FBGs are periodical perturbations of the fiber's core refractive index placed orthogonally to the fiber's longitudinal axis on a specific location. This causes a reflection of a certain portion of the light spectrum known as Bragg wavelength, while the rest of the wavelengths of the spectrum are transmitted. The Bragg wavelength is defined as twice the product between the grating periodicity and the waveguide mode's mean effective refractive index. When the fiber is correctly attached to the material of interest, stresses cause changes on sensor's grating periodicity, which results in a shift of the reflected wavelength. The position of the Bragg wavelength on a specific time can be then related to the underlying material strain at the sensor location.

FBG sensors have several advantages against traditional electric gages as they are lightweight, small components that are immune to interferences caused by electromagnetic radiation. Also, they have a long lifetime, a safe electrically-independent operation, and the capability to be multiplexed as one optical fiber can have many FBGs