Structural health monitoring and impact detection for primary aircraft structures

Eric Kosters and Thomas J. van Els

High-speed, synchronous interrogation using multiple-fiber Bragg grating sensors enables design and delivery of robust inspection and analysis systems.

The increasing use of thermoplastic carbon fiber-reinforced plastic (CFRP) materials in the aerospace industry for primary aircraft structures, such as wing leading-edge surfaces and fuselage sections, has led to rapid growth in the field of structural health monitoring (SHM). Impact, vibration, and load can all cause failure, such as delamination and matrix cracking, in composite materials. Moreover, the internal material damage can be invisible to the human eye, making inspection of and clear insight into structural integrity difficult using currently available evaluation methods. Here, we describe the detection of impact, its localization, and its potential damaging effects on materials and structures by high-speed interrogation of multiple-fiber Bragg grating (FBG) sensors\(^1,2\) mounted on a composite aircraft component.

At Technobis Fibre Technologies (TFT), we have developed, industrialized, and released an FBG interrogator with specific performance characteristics that are well suited to the requirements of an SHM system for composite primary aircraft structures. Our interrogator is called Deminsys (Demultiplexing Interrogation System). The key characteristic of the device is the simultaneous readout of up to 32FBG sensors (four channels with, typically, eight sensors per channel) at a maximum sampling frequency of 19.3kHz each.\(^3\) The system is self-calibrating, meaning that it can be coupled to preinstalled fibers in any construction. Figure 1 shows the optical design concept of the Deminsys optical channels in schematic form. Working with several knowledge partners within the aerospace industry, we are developing different solutions for monitoring aspects of the structural integrity of aircraft structures and materials. One of these solutions is what we call impact detection: determining impact location and energy to assess potential damaging effects. We compare the impact energy level with the structural strength of the exposed surface, which in turn facilitates decision making regarding next steps in accordance with common condition-based maintenance concepts.

Impacts cause local elastic deformations in the affected material surfaces that propagate through the structure like waves.

Continued on next page
These local deformations are measured by FBG sensors placed at several locations on an aircraft part. Combining and comparing the information relayed by the sensors enables the system to calculate the location and energy level of the impact.

We designed and built an experimental test setup consisting of a composite aircraft component equipped with an FBG sensor network of four sensors in one optical fiber, our lightweight, small, high-speed Deminsys interrogator, and a data acquisition and processing platform. The composite aircraft component currently used is a thermoplastic wing-control surface that consists of two skin plates, four ribs, two spars, and a folded plate to cover the trailing edge (see Figure 2).

The test setup provides real-time feedback on impacts and the condition of the material. We began by carrying out a proof of concept using a flat, homogeneous composite plate as a test specimen. We placed FBG sensors at the outer edges of the long side of the plate (see Figure 3). Impacts were generated by striking the specimen with a hammer. We calculated the position of the impacts based on a time differential equation of the sensor signals. The impact intensity level was determined according to the weighted sensor strain amplitude level. The 19.3kHz sampling speed makes it possible to evaluate the sensor signals with a time resolution of 51μs. We were able to determine the location of impact with an accuracy of ~5cm.

For the next phase we selected a complete composite wing-control surface for the setup with the aim of identifying the influencing parameters of the elastic wave propagation and sensor detection through experimental analysis. We attached four FBG sensors to the wing-control surface, which had outer dimensions of 1200×500mm (see Figure 2). Figure 4 shows the measurement signals, representing the mechanical strain versus time, following a simulated impact. The difference between the arrival time of the impact waves at the different sensors provides a measure of the impact location. The sum of the weighted strain amplitude levels of the sensors calculates the impact energy.

We demonstrated the repeatability and accuracy of the method by comparing the measurement signals for five tests of one FBG sensor. For the timing accuracy, we found ±1 measurement sample deviation across the five consecutive tests, which equals an accuracy of < 51.8μs. For the strain amplitude measurement, the deviation is less than 10% (see Figure 5).

Development activities are in progress, and initial results confirm the expected good potential of the method for SHM. In
addition to these initial results, we found that impacts below 1.0 Joule can be detected across the wing section (see Figure 6), a layout with four sensors shows promising results, and the ribs and spars in the structure have a significant influence on the behavior of the elastic impact waves. The location of an impact on a surface can in principle be determined with a minimum of three FBG sensors. We use four because the redundant sensor helps to validate the impact location provided by the other three sensors and to more precisely calculate it. Finally, the prediction of the impact location shows good correspondence with the actual point of impact.

Our investigations are currently focusing on different parameters related to elastic wave-propagation characteristics such as propagation speed and deflection amplitudes. These parameters include the mechanical properties of the structural material (i.e., stiffness at the impact and sensor locations as well as internal components such as spars), the energy of the impact, the velocity of the object on impact, and the hardness of the object. A better understanding of the effect of these parameters on elastic wave propagation will help to improve our impact analysis algorithms and methods.

Author Information

Eric Kosters and Thomas J. van Els
Technobis Fibre Technologies
Eindhoven, The Netherlands

References