



Structural health monitoring and impact detection for primary aircraft structures

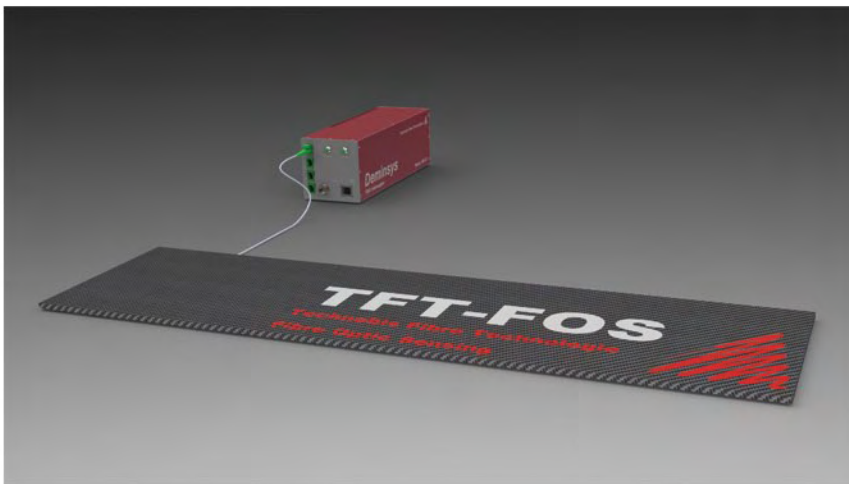


Figure 1. Impact analysis setup with flat homogeneous composite plate.

SHM system

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. 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 20kHz each. The system is self-calibrating, meaning that it can be coupled to preinstalled fibres in any construction. Figure 2 shows the optical design concept of the Deminsys optical channels in schematic form. Different solutions for monitoring aspects of the structural integrity of aircraft structures and materials are being developed within TFT in close cooperation with several knowledge partners within the aerospace industry. 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.



Short description

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

The increasing use of thermoplastic carbon fibre-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 occur without being visible 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-fibre bragg grating (FBG) sensors mounted on a composite aircraft component.

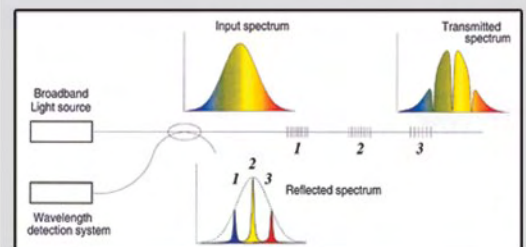


Figure 2. An superluminescent LED (SLED) transmits a broadband light spectrum through a glass fibre. The Fibre Bragg Grating (FBG) sensors in the fibre reflect a specific wavelength of the light signal back to the Deminsys system, which determines the value.



Specifications



Impact analysis

Impacts cause local elastic deformations in the affected material surfaces that propagate through the structure like waves. 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. 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 1). Impacts were generated by striking the specimen with a hammer. The position of the impacts was calculated based on a time differential equation of the sensor signals. The impact intensity level was calculated according to the weighted sensor strain amplitude level. The 20kHz sampling speed makes it possible to evaluate the sensor signals with a time resolution of 51 μ s. We were able to determine the location of impact with an accuracy of ~5cm.

For the next phase we selected a complete composite wingcontrol 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 1200x500mm. Figure 3 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 a measurement accuracy of < 51.8 μ s. For the strain amplitude measurement, the deviation is less than 10% (see Figure 4).

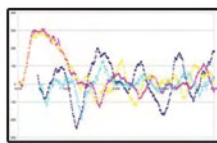


Figure 3. FBG measurement signals following an impact. The elastic wave clearly reaches every FBG sensor at a different moment in time. This difference in time makes it possible to calculate the actual location of impact.

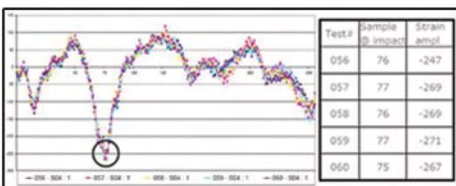


Figure 4. Results of five tests of one FBG sensor following an impact event. The table columns indicate test number, sample number on which the impact event is detected, and strain amplitude level at the time of impact. The graph and table show a good level of repeatability of the measurement setup.

Results

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 5), 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 and internal components of the structure's configuration, such as spars and stiffeners), 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.

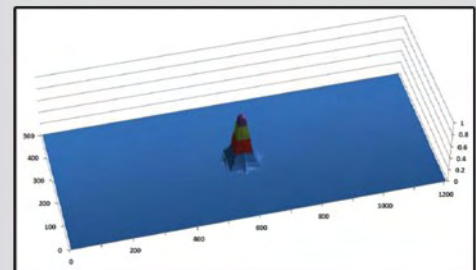


Figure 5. Result of impact detection

All names mentioned in this datasheet are protected and may only be used in other publications with the explicit permission of their respective owners.