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DAMAGE DETECTION IN COMPOSITE LANDING GEAR COMPONENT USING FREQUENCY RESPONSE METHOD

Gianluca BREGLIO[1], Francesco. FIENGA[1], Andrea IRACE[1], Fabio MENNELLA[2], Luigi PETRAZZUOLI[2], Armando LAUDATI[2], Michele GIORDANO[3], Alfonso MARTONE[3]

[1] Dipartimento Di Ingegneria Elettrica E Tecnologie Dell'informazione
Università di Napoli
P.le Tecchio, 80125 Naples ITALY

[2] OptoSmart srl.
Via Pontano, 61, Naples, ITALY

[3] Institute for Composite and Biomedical Materials,
National Research Council of Italy
Ple E Fermi, 1 80055 Portici- Naples, ITALY

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ABSTRACT

In this work, the damage identification for a composite landing gear component has been performed by the study of its dynamic behaviour. Fiber optic sensors were used for acquire the vibration signature of the system in its undamaged condition and during a high energy impact. The vibration test on the damaged component underlined a modification on the system response which should be considered for the health status assessment.

1 INTRODUCTION

Existence of structural damage in an engineering system leads to modification of the vibration modes, this effect offers the possibility of using data from dynamic testing to detect, locate and quantify damage. Damage of a component may be detected using frequency response of the structure by studying the shift in natural frequencies of the system. In landing gear applications a torque link is used to prevent the landing gear from shimmying during landing operations.

The drag brace is one of the main load carrying elements of the landing gear and is loaded both in tension and compression [1] during take-off and landing operations. The use of a composite material should target to both weight reduction and stiffness increase however their poor transverse and shear properties[2] introduces concerns about the impact behaviour of the component. The introduction of a monitoring system would improve the safety replacement of the metallic component. Fiber Bragg Gratings (FBG) strain gauges are ideal candidates for the structural health monitoring of composite component since they should be embedded within the structure without threaten its strength [3].

The activities are addressed to the identification of a possible damage of the component by studying the dynamic response of FBG during vibration tests. In order to carry out the analysis both the random vibration and the sine sweep vibration have been considered. Since FBG does not affect the stiffness and strength of the component, and thanks to their multiplexing feature are considered to map the deformation of the component. FBG sensors have been successfully applied as alternative to accelerometers for the assessment of structural damages [4]

Vibration-Based methods have been successfully considered for the study of composite components. The damage identification should be performed mainly by modelling the component or through the deviation detected respect to the intact system [5,6]. In the first approach the dynamic modelling of the component is used for assess the health status and the condition, while the latter does not require any modelling Methodologies which discard the numerical model in view of the complexity of material properties and their statistical distribution could be useful applied to efficiently investigate composite component and structures. The presence of delaminations within the component has been related to changes in its dynamic behaviour such as natural frequencies and/or damping [7–9].

Methods based on the time-domain vibration signatures represent an attractive alternative, by these methods the signal analysis is combined with statistical characteristic of the component to investigate its status [10,11]. By the latter approach there are any assumption on the linear behaviour of the component and only require a measure on the undamaged system to be assumed as baseline for further investigations.

This work describes the experimental investigation focusing on the vibration testing of the composite drag brace component. The undamaged component has been tested to provide a baseline for the structural health status assessment. The component was damaged by high energy impact before further tests. The random vibration tests was not able to detect the damage on the component, while the analysis carried out by sine sweep tests underlined modification of the dynamic response of the damaged component.

2 EXPERIMENTAL SET-UP AND PROCEDURE

The vibration tests were performed on the drag link component for the aircraft landing gear system. Boundary condition were applied to replicate the real operative condition for the system, a side is bolded on a flange fixed on the vibrating plate, the other side is pinned with a weight reproducing the landing gear components. To induce the oscillations in the structure a single shaker system is attached. Vibration characteristics of the components has been recorded by 2 tri-axial accelerometers which have an average sensitivity of 0.06 mV/g and a range of ± 10g.

Figure 1 – Experimental test set-up

Figure 1 reports the vibration test set-up. In order to measure the component response to the dynamic excitation, fiber optical deformation sensors (Fiber Bragg Grating - FBG) were installed on the component. Position of sensors is detailed in the Figure 2. A total of four FBG were bonded to the component in a section to record the deformation during the tests.

The vibration tests were carried out by recording the system response to random vibrations and to swept-sine solicitation at a sampling rate of 2500 Hz in the frequency range of 5-1000 Hz. Frequency response functions are computed to determine the resonant frequencies and the associated mode shapes and damping coefficients. Vibration tests were performed according to the MIL-STD-810G-514.6 procedure.

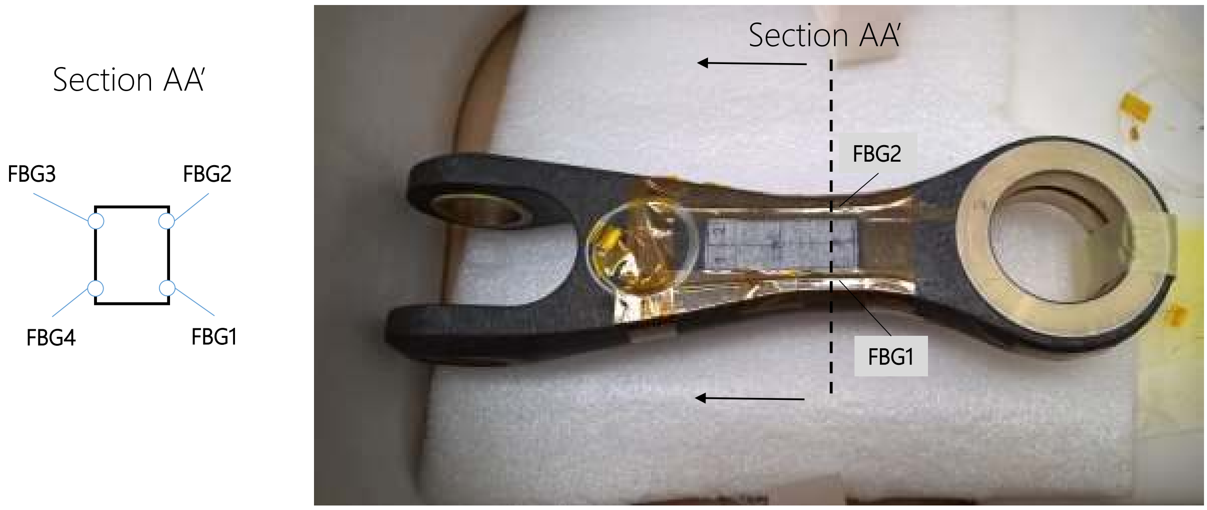


Figure 2 – FBG installation on composite drag link

Impact test were carried out by a modified Charpy impact system. By counter rotating the pendulum hammer it is possible to install a cylindrical block having different sizes and shapes, usually a hemispherical head. The component was located on the vertical surfaces of the supporting bases of the pendulum, at the height of the notched plane of the hammer (0° angle). The electromagnetic brake limits the phenomenon of bouncing. The drop masses have different geometries and weight according to the different energy level and damage required for the test.

FBG sensors were interrogated by a Dynamic Optical Sensing Interrogator SM 130-700 with enhanced bandwidth from MICRON OPTICs Inc., which has a maximum sampling rate of 2500Hz. The effective refractive index of the core and spatial periodicity of the grating are both affected by the changes in temperature and strain.

$$\frac{d\lambda}{\lambda} = (1 - P_e)\, d\varepsilon + (\alpha_{glass} + \zeta)\, dT \qquad (1)$$

Where Pe is the elasto-optic coefficient (0.22 adimensional) while the thermal sensitivity is about 6.67 10-6 /°C for optical fibre whose core is silicon dioxide. Actually, the temperature variation should be discarded due to the short duration of the test. The deformation experienced by FBG sensors is then related directly to the shift in peaks recorded against the frequency.

3 RESULTS AND DISCUSSION

A forced vibration test has been performed using sinusoidal (harmonic) loading over a frequency range of 5-500 Hz which correspond to the environment solicitation that would experience the component. The component has been exited with harmonic loading such that at certain frequencies it experiences resonance. Figure 1 reports the acceleration spectrum which is applied to the composite drag brace during the test. The component has been firstly tested as manufactured, then after an impact event in order to highlight modification in its dynamic behaviour.

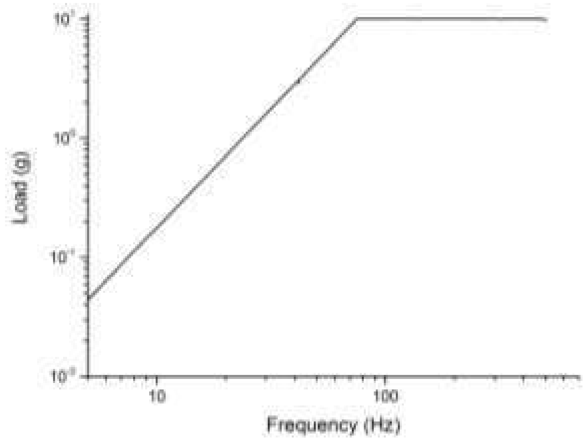


Figure 3 – Acceleration spectrum during the vibration tests

Four FBG sensors have been bonded on the component according to the installation schematic reported in the Figure 2. In the section AA', two deformation sensors for side have been integrated according to the symmetry axis of the component. The strain experienced during the test on the whole component are reported in the Figure 4.

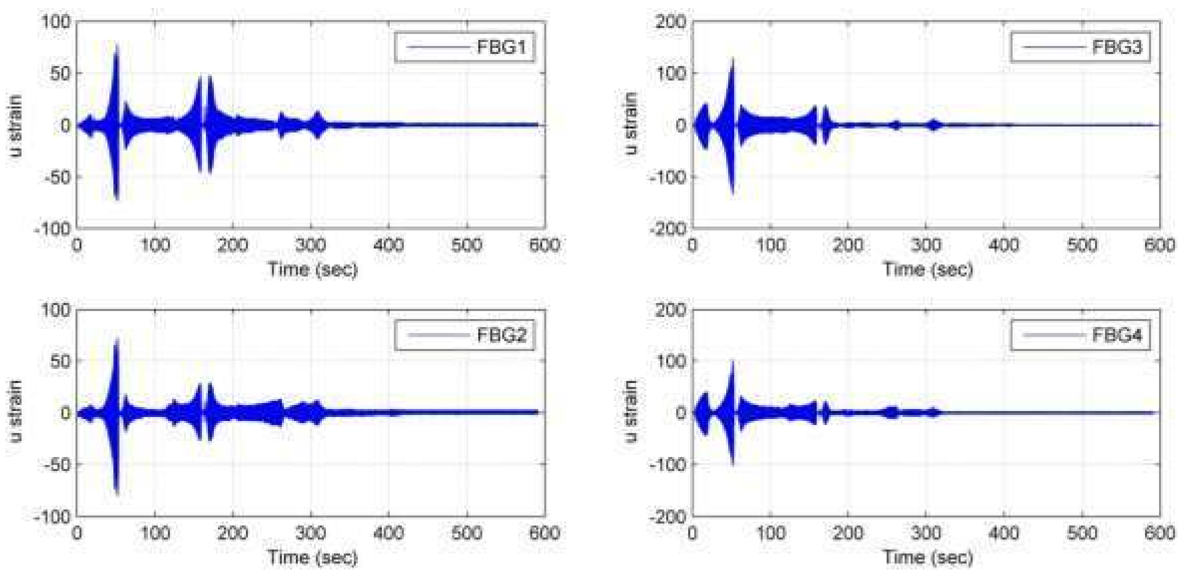
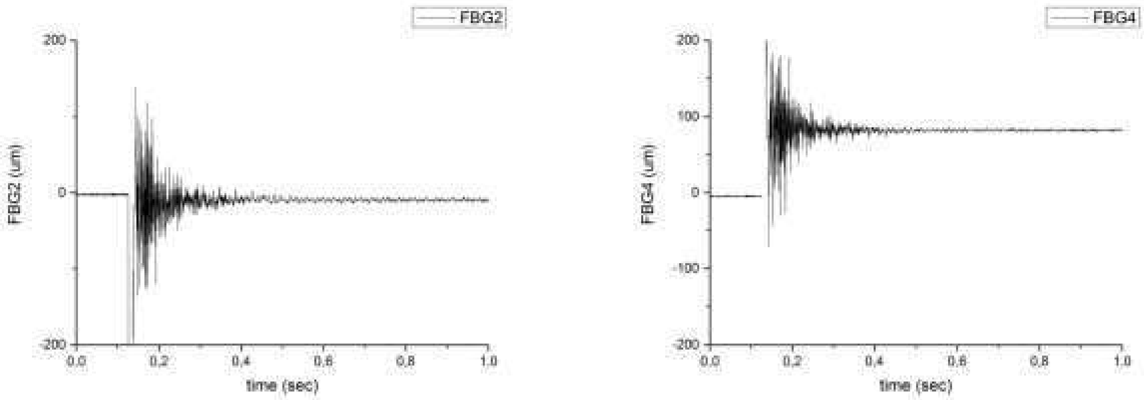


Figure 4 – Strain history during sine sweep test

During the test a little disequilibrium in the deformation intensity between sides of the component it is recorded. Sensors upon the front side exhibited lower deformation.

Later, the component has been impacted in order to induce a damage in the component. The hammer hit the component on the front side in the area closed to FBG1 and FBG2 sensors (Figure 2).

Figure 5 reports the deformation measured by sensors during the impact test. The picture on the left side describes the behaviour of sensors installed on the impacted side, while the picture on the right side reports the response measured on the opposite side. It is worth to notice that sensor FBG4 reported a residual deformation (about 90 με) while other sensors reported negligible residual strain (less than 10 με).



a) b)

Figure 5 – Deformation recorded during the impact test. a) sensor on the impacted side, b) sensor on the opposite wedge

After the impact the drag link was tested again in order to highlight modification of its structural response to vibration. Figure 6 reports the frequency domain analysis of vibration test on the intact (blue line) and on the impacted component (red line) for the sensor FBG4.

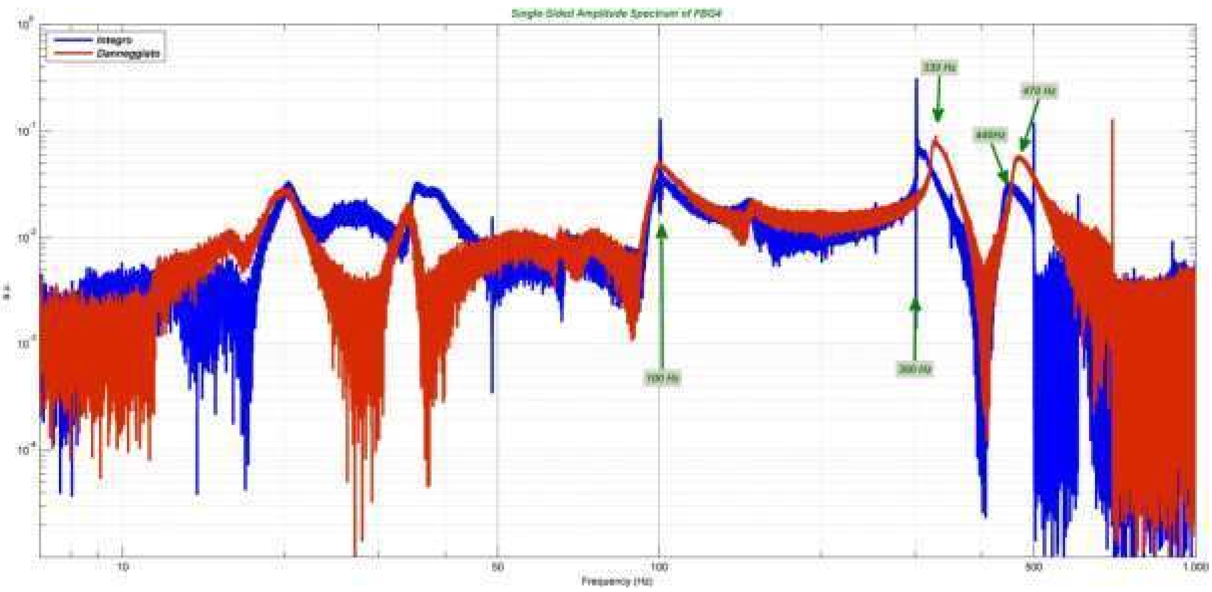


Figure 6 – Comparison between sine sweep tests for sensor FBG4 before and after the impact event.

All the sensors showed a modification of strain spectrum for the impacted component. The main differences are observed at the higher frequencies. Above 300 Hz the frequency peaks shift approximately of 30Hz. In the lower frequency range the peak frequencies do not change but modification on the amplitude is evident.

Random vibration test were also carried out in order to investigate the component response in a wider frequency range (1-1000Hz). A major difference between sinusoidal vibration and random vibration lies in the fact that for the latter, numerous frequencies may be excited at the same time.

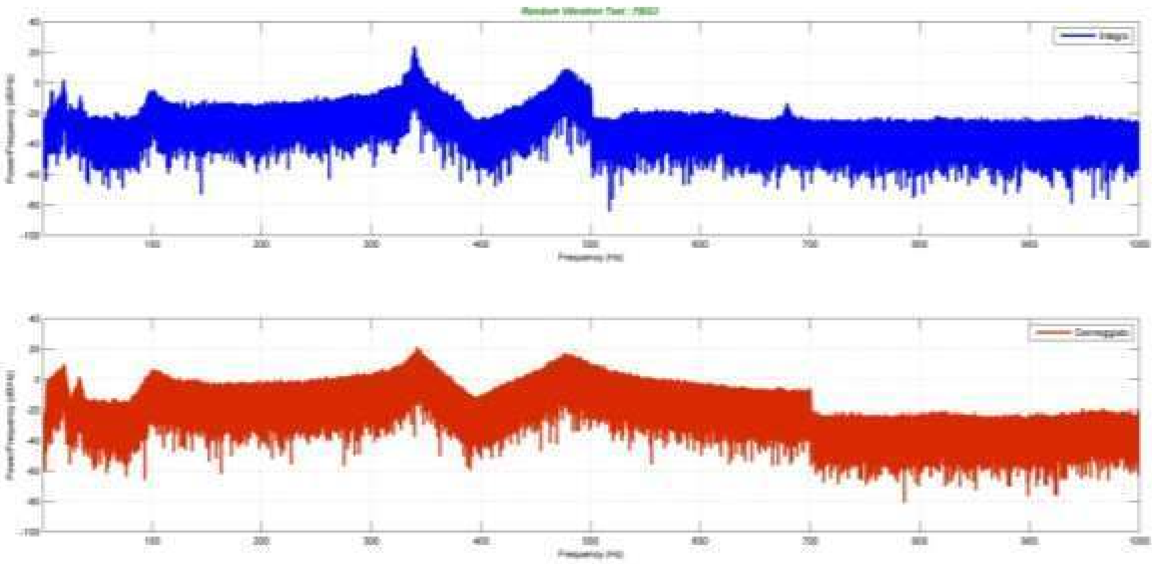


Figure 7 – Random vibration spectra for pristine and impacted component recorded on FBG4 sensor

Figure 7 reports the frequency domain comparison between for the component before and after the impact event for the sensor FBG4, similar behaviour was recorded for the others. Such test revealed the inability to give information about the healthy status of the component. Spectra recorded for random vibration tests did not exhibit clear differences.

4 CONCLUSIONS

A composite component is studied in this work as the retrofit of a metallic drag brace for civil aircraft industry. FBG sensors have been considered for identify the damaged status. The dynamic behaviour of the component have been studied by means of sine-sweep and random vibration tests. To induce a damage within the component a modified charpy hammer has been used. The impact has induced permanent strain within the component, the impacted side recorded slight negative permanent deformation, while the opposite side recorded positive residual strain.

The frequency response of the component showed a modification of the natural frequencies which allowed to identify the damage in the structures. The spectrum exhibited a clear modification within the range 300-500 Hz which identify the damaged scenario.

The comparison between the behaviour after the impact event has revealed a frequency shift of the relevant peaks of about 30Hz for the impacted component. All the FBG exhibited a similar trend, leading to a possible identification of a damaged component.

The methodology presented proved to be a simple and effective procedure from which the modal characteristics of a component could be determined.

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