Damage Detection using Fibre Bragg Grating Sensors

Marco WEIS, Jonas HOFLIN, Peter DEIMEL, Rudolf BILGRAM, EADS Deutschland GmbH, Munich, Germany,
Klaus DRECHSLER, Institute of Aircraft Design, University of Stuttgart, Germany

Abstract. Motivated by a reduction of maintenance costs and the enabling of new design criteria aircraft manufacturers are developing structure-integrated damage sensor systems. In this paper the application of Fibre Bragg Grating Sensors (FBGS) for damage detection is investigated. Acting as an optical strain sensor, FBGS will detect a change in strain distribution influenced by a growing crack or delamination in the monitored structure. Making the step to determine damage size and location from a measured strain distribution requires exact knowledge of the structural behaviour. In FEM-calculations the optimum positions for applying FBGS can be identified so that the sensors do not break in case of a crack but also produce a clearly evaluable strain signal. In this work, samples close to real aircraft structures were instrumented with a strategically arranged grid of FBGS to ensure maximum information with a minimum of sensors. Measurements were performed during and after an impact test. It could be demonstrated that the resulting damage is detectable by the sensor system. Appropriate data interpretation allows for the conclusion on damage size and location.

Introduction

In this work, FBGS were applied on the CFRP (Carbon Fibre Reinforced Plastic) surface of an aircraft fuselage stringer stiffened panel. The objective was to detect impact damage by measuring the change in strain during and after the impact. Making the step to determine damage size and location from a measured strain distribution requires exact knowledge of the structural behaviour. Therefore, FEM calculations need to be performed to get information about the inspected strain field whereas data analysis is not part of this paper. In this investigation FBGS have been applied for two objectives:

1. Measurement of change in strain during the impact
2. Measurement of permanent deformation (residual strain) caused by the impact damage

Impact Test

Investigations were performed on a CFRP panel in an area of 400mm x 400mm which was reinforced with two parallel running so called omega stringers. The surface where the stringers are located represents the inside of the aircraft structure whereas the impact damage will be introduced from the outside. The optical fibre was surface-bonded with an adhesive which had been identified to be adequate for CFRP application after former extensive testing. Measurements have been performed using an optical sensing interrogator with a sampling rate of 250Hz. The impact was monitored with an optical fibre with 11 gratings bonded on the inner surface of the panel as can be seen in Figure 1.

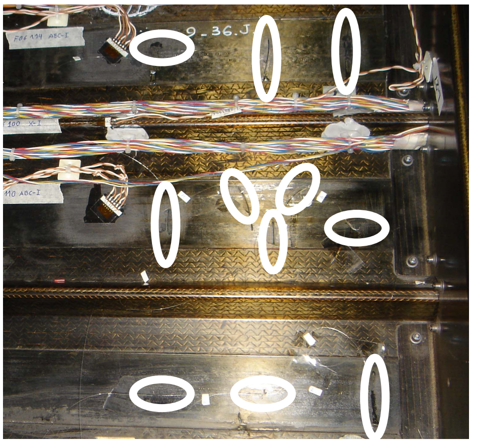

Figure 1. Photo of bonded FBGS, the ellipses mark the locations of the sensors

Figure 2 shows the strategic sensor application. The dashed lines symbolise the omega stringers that cross the measured area and divide it into three zones:

Zone 1: Underneath the point of impact, monitored with FBGS 1, 2 and 3
Zone 2: Nearest to the point of impact, monitored with FBGS 4, 8, 9, 10 and 11
Zone 3: Above the point of impact, monitored with FBGS 5, 6 and 7

The FBGS are numbered by G1-G11. G1 (Grating 1) reflects the lowest wavelength, G2 the second lowest, etc. The given lengths describe the distances between the impact point and the gratings respectively. The impact will be carried out from the outside of the fuselage; the point of impact is marked by a star.

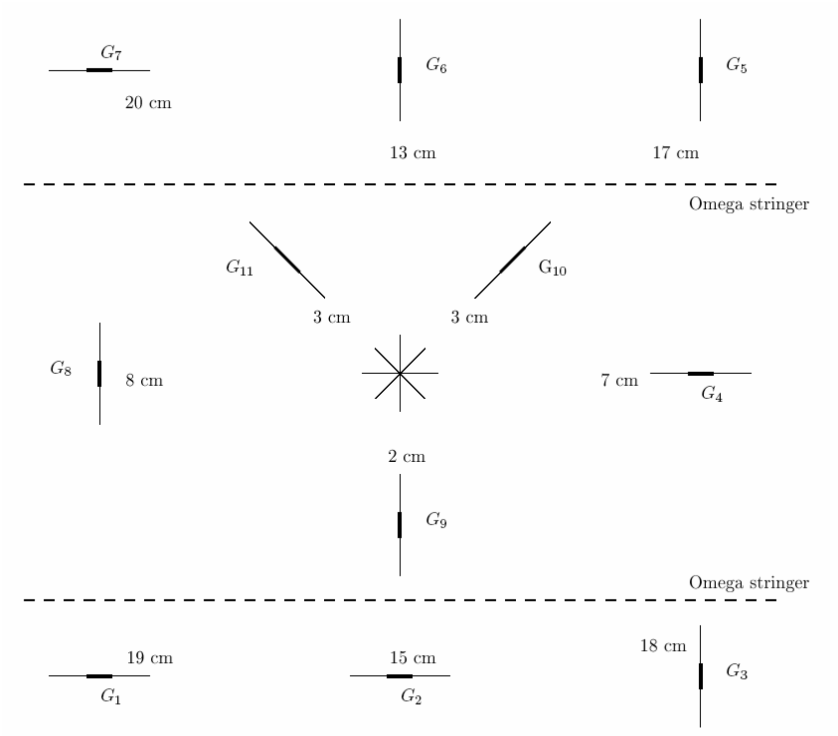

Figure 2. Strategic sensor application

The impact took place 41.03s after the measurement was started and has been of such high energy that the fibre and some FBGS were torn away from the surface.

Results

The results are plotted in diagram form. Each FBGS is represented by a line, showing strain vs. time. The lines are marked with a number, which corresponds to the number of the FBGS. For all diagrams the time is plotted on the X-axis in the unit seconds and the strain is plotted in the unit micro strain on the Y-axis. A positive value on the strain axis corresponds to tensile strain and a negative value corresponds to compressive strain.

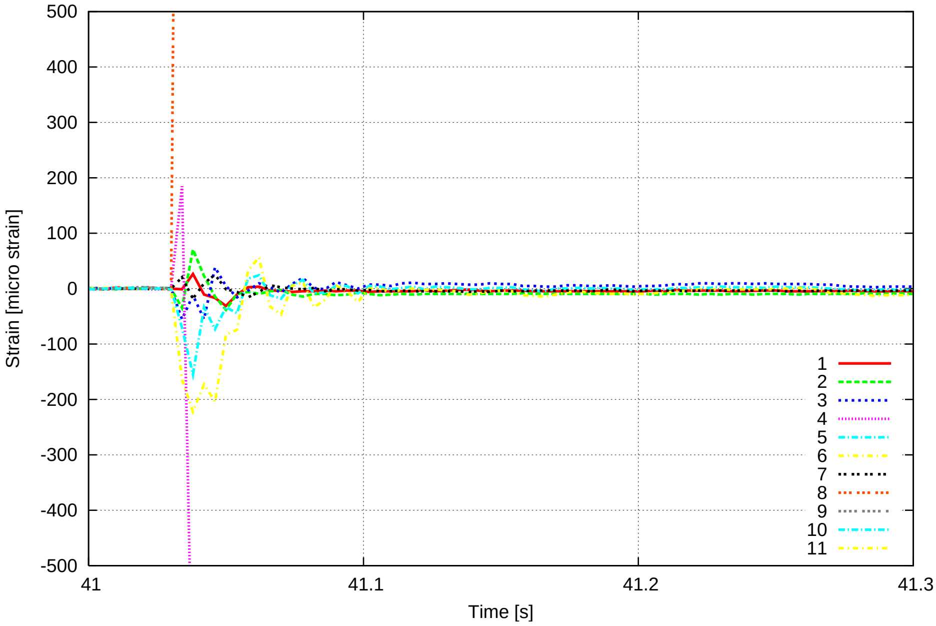

Figure 3. All measurement values from the FBGS plotted in the same diagram

FBGS in zone 1

The FBGS 1, 2 and 3 were bonded underneath the point of impact. Figure 4 clearly shows a change in strain after approximately 41s. The peak in strain right after 41s can be correlated to the time of impact. After the impact, permanent deformation has arisen. This can be observed in Figure 5 after 41.1s. Here, the strain values diverge from zero for all three FBGS, which indicates permanent deformation. In Figure 5 the measurement values from FBGS 1, 2 and 3 are plotted over a time interval of 0.3s: right before, during and after the impact.

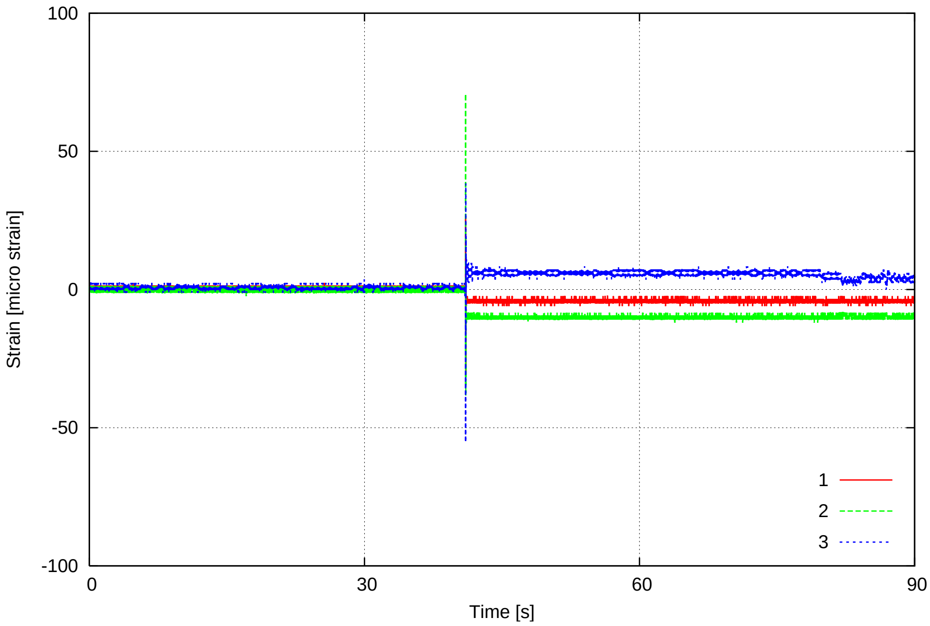

Figure 4. Overview-diagram of measurement values from FBGS 1, 2 and 3

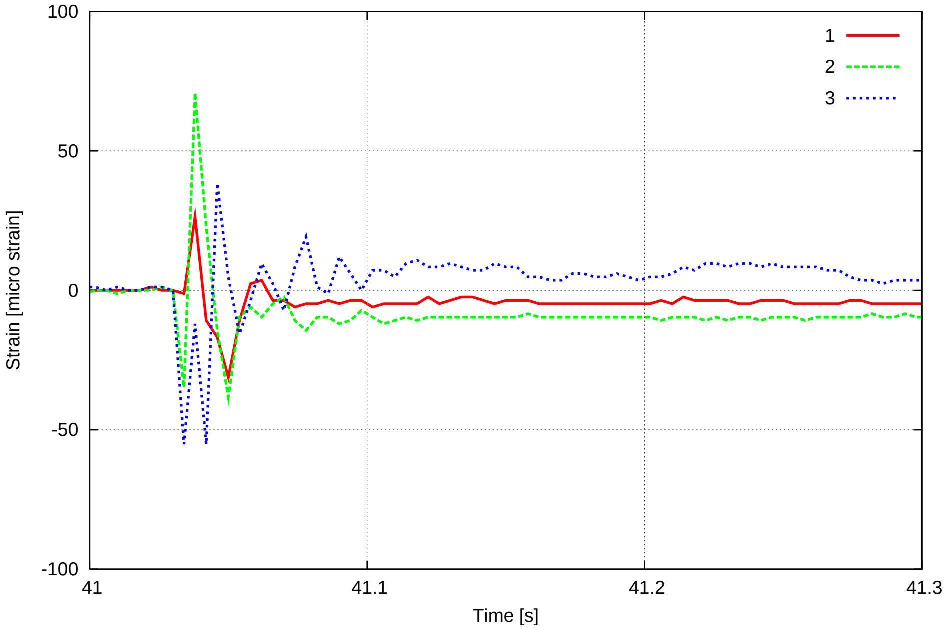

Figure 5. Diagram of measurement values from FBGS 1, 2 and 3 during the impact

FBGS in zone 2

The FBGS bonded closest to the impact were the FBGS 4, 8, 9, 10 and 11. Thus, these sensors were exposed to the largest impact energy. In Figure 6 the measurement values from all FBGS in zone 2 are plotted. Immediately after the impact the fibre was broken and no measurement signals from FBGS 9, 10 or 11 were obtained any more. From FBGS 7, one measurement value was obtained before it also lost its signal. This signal shows a large extracting strain value. The connecting fibre to FBGS 4 was not damaged which displays a great compressive strain after the impact. Figure 7 shows the strain immediately after the impact for the FBGS in zone 2.

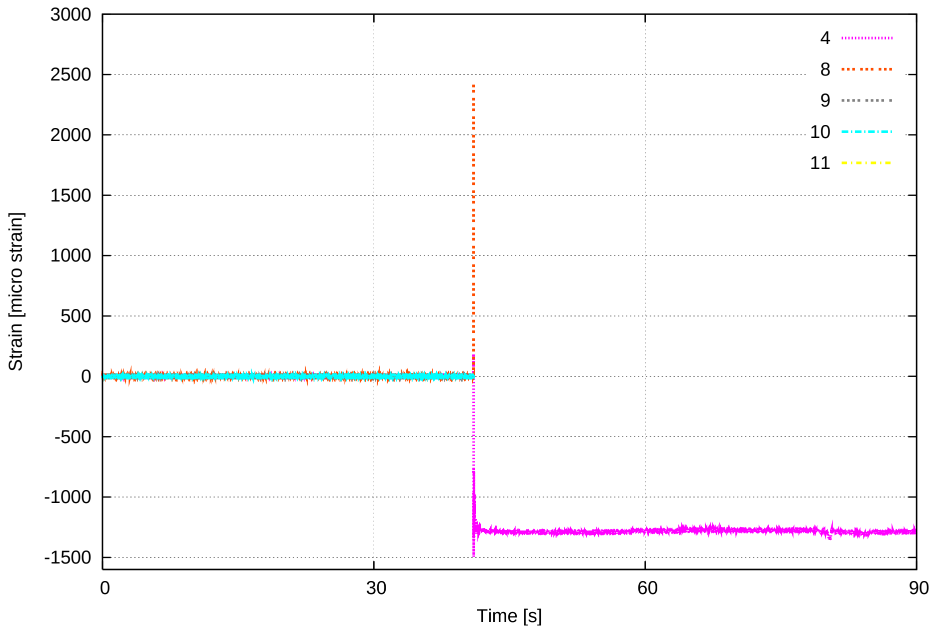

Figure 6. Overview-diagram of measurement values from FBGS 4, 8, 9, 10 and 11

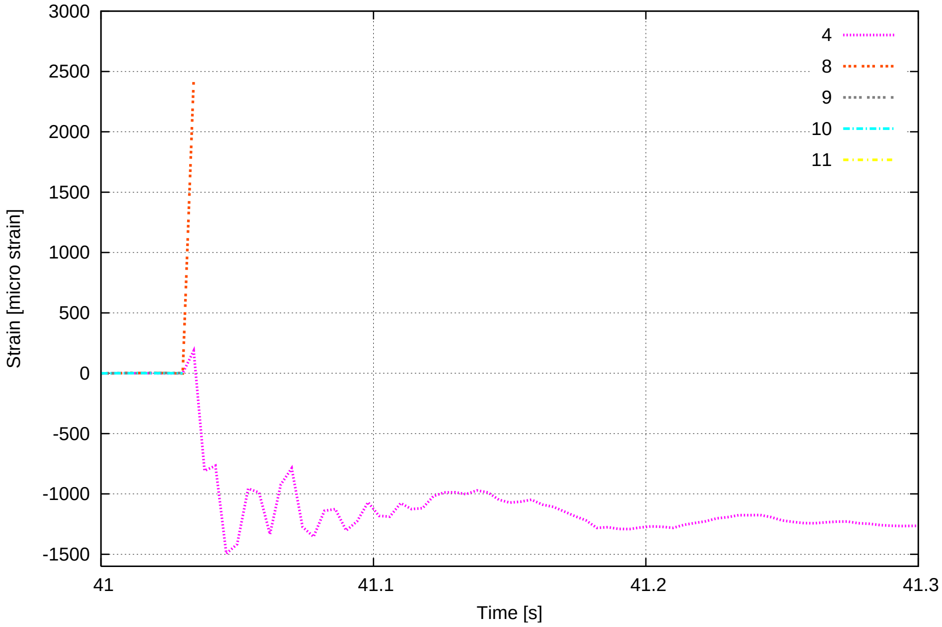

Figure 7. Diagram of measurement values from FBGS 4, 8, 9, 10 and 11 during the impact

FBGS in zone 3

The FBGS 5, 6 and 7 were bonded above the point of impact. In Figure 8 it can be seen that permanent deformation occurs after the impact. The strain diverges from zero for FBGS 6 and 7. Figure 9 shows the measurements during and right after the impact. All three FBGS show significant change in strain, especially FBGS 6 that was bonded straight above the point of impact.

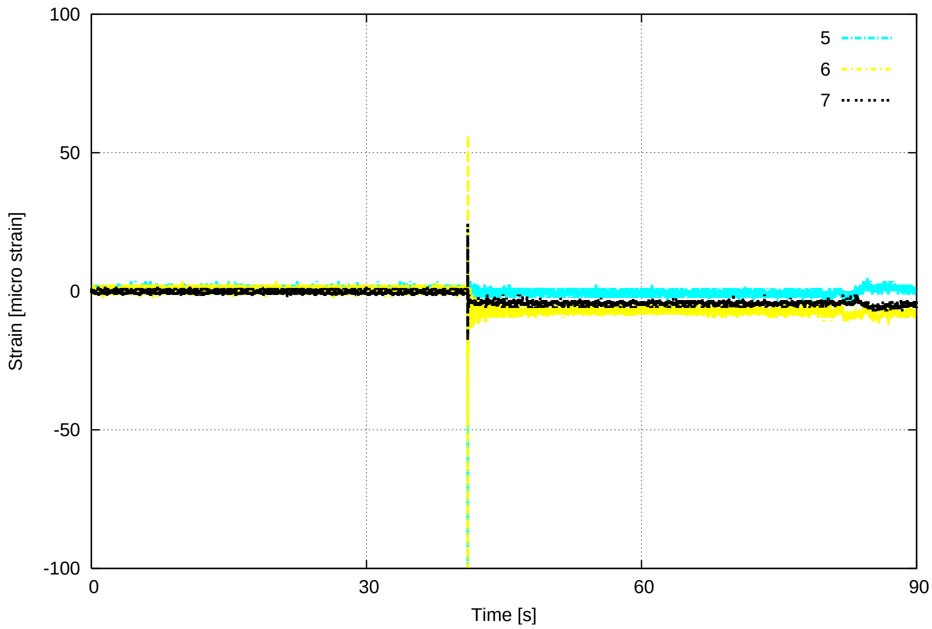

Figure 8. Overview-diagram of measurement values from FBGS 5, 6 and 7

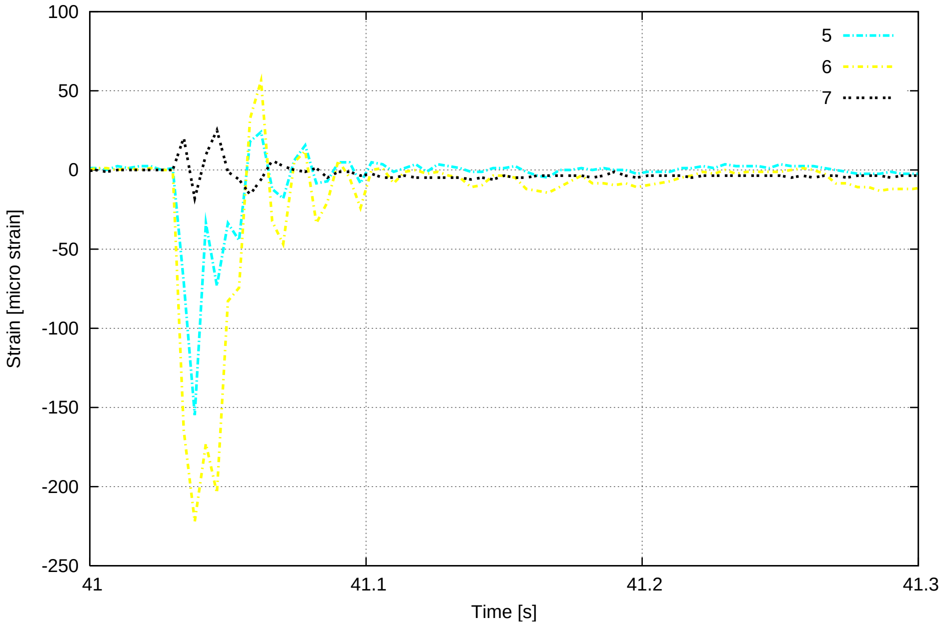

Figure 9. Diagram of measurement values from FBGS 5, 6 and 7 during the impact

Conclusions

The feasibility of Fibre Bragg Grating Sensors for impact monitoring could be shown in this paper. The impact causes a peak in strain on the sensor locations. Permanent deformation of the FBGS is an indication for an impact when the surface has been deformed to such extent that after force release, a remaining displacement exists and the strain values diverges from their values before the impact. The FBGS 7 detects the impact 200mm away from the point of impact.

The improvement of damage characterisation in size and location requires a better knowledge of the structural behaviour. Therefore, FEM calculations have to be adjusted to the experimental results. For an online monitoring of the impact event itself, an optical sensing interrogator with a higher sampling rate (>500Hz) will be used in future tests.

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