EAN 2013
51th conference on experimental stress analysis

The use of Fiber Bragg Grating Sensors During the Static Load Test of a Composite Wing Structure

Milan Dvorak[1, a], Miroslav Kabrt[2, b] and Milan Ruzicka[1, c]

[1]Czech Technical University in Prague, Faculty of Mechanical Engineering, 166 07 Praha 6, Technicka 4, Czech Republic

[2]Vanessa Air spol. s r. o., 570 01 Litomysl, Kornicka 86, Czech Republic

[a]milan.dvorak@fs.cvut.cz, [b]vanessa@lit.cz, [c]milan.ruzicka@fs.cvut.cz

Keywords: optical sensor, Fiber Bragg Grating sensor, FBG, composite, wing, embedded sensor.

Abstract. The article describes process of implementation of optical Fiber Bragg Grating (FBG) sensors into the composite wing structure and their behavior during the strength test. The wing is of all-composite construction. The upper and lower skins are made of glass/epoxy composite. The spar caps are made of carbon/epoxy unidirectional composite. Optical fibers were integrated directly into the spar caps and into the adhesive joints. They were oriented in parallel with the main spar axis. The first optical fiber with chain of multiple FBG sensors was integrated into the structure of upper spar cap. Another FBG chain of FBG sensors was located in the adhesive joint of lower spar cap and shear web. The wing was instrumented with strain gages as well. Strain gages were glued to the sides of the spar caps. Static load was produced by a hydraulic actuator. Experimental results from strain gages and FBG sensors were compared with the results of the analytical analysis of the wing.

Introduction

The goal of the experiment was to test the suitability of integrated optical sensors to monitor the cantilever wing beam. It is a commonly used type of demountable continuous wing. Its working principle is pictured in Fig. 1. Beside the demountability the main advantage is in elimination of transmission of bending moment into the fuselage. Critical component of the wing is end of cantilever wing spar, especially in an area where the root rib is connected to the upper spar cap; and an adhesive joint of shear web and spar caps. Due to the large change in the stiffness of the wing spar on its end (from the root rib to the airplane axis) and drop of a shear force, the wing spar usually brakes near the root rib during the test loading (see Fig. 1).

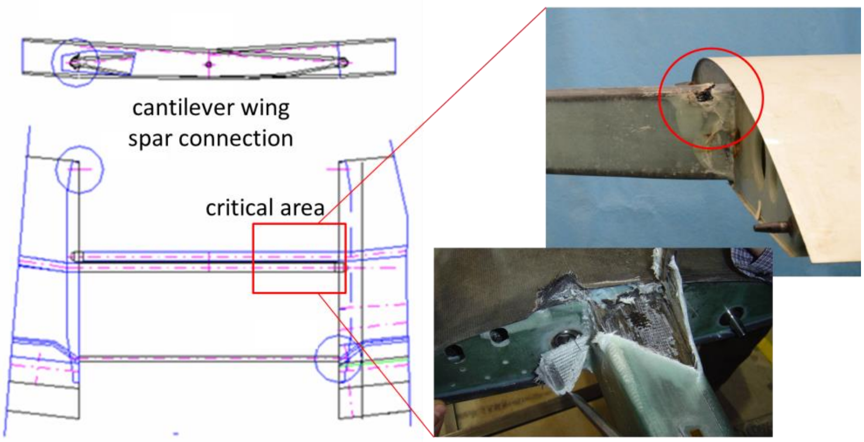

Fig. 1 Principal of demountable cantilever wing, with details of critical area of a cantilever spar.

Main requirements for optical sensors are the following: they must survive manufacturing process of the wing, they must allow monitoring of critical parts without influence on their strength, they

must be an integral part of structure. Fiber optic based sensors are light with small dimensions, they are immune to electromagnetic interference and do not present an ignition hazard. Optical sensors have multiplexing capability, which means that a number of sensors can be placed in a one optical fiber to reduce weight of cabling. Additionally they can be embedded into the composite structure, which makes them suitable for Structural Health Monitoring (SHM) purposes [1]. FBG sensors are currently the most attractive of the fiber optic sensors for various spacecraft applications [2], [3]. FBG sensor working principle is based on a periodical change in refractive index in a fiber optic core. This so called "grating" reflects part of the light back, the rest of light is transmitted. Mechanical loading of the material or temperature change induces a change in the Bragg wavelength which is proportional to the deformation. For more detailed description of the method see [4], [5].
Because of the above mentioned properties the FBG sensors were chosen as the most suitable solution for future SHM system of critical places of all-composite ultra-light aircraft wing. Integrated sensors would give the manufacturer possibility to evaluate the damage of the aircraft after the for example harsh landing, and thereby reduce the need to replace expensive parts such as wing.

Strain Sensors Installation

Composite wing was instrumented with FBG sensors for strain monitoring of spar caps and surface-mounted strain gages, which were used as a reference for FBGs. First optical fiber with chain of FBG sensors was embedded into the structure of carbon/epoxy upper spar cap during its manufacturing process. FBG sensors are oriented in a longitudinal axis, so they can measure elongation/compression of a cap. Second optical fiber (again with a chain of FBGs) was placed into the adhesive joint of a lower spar cap and spar web. Strain gages were glued to the both sides of the upper spar cap, to measure distribution of strain in the same area as a FBG chain. Location of sensors is schematically shown in Fig. 2.

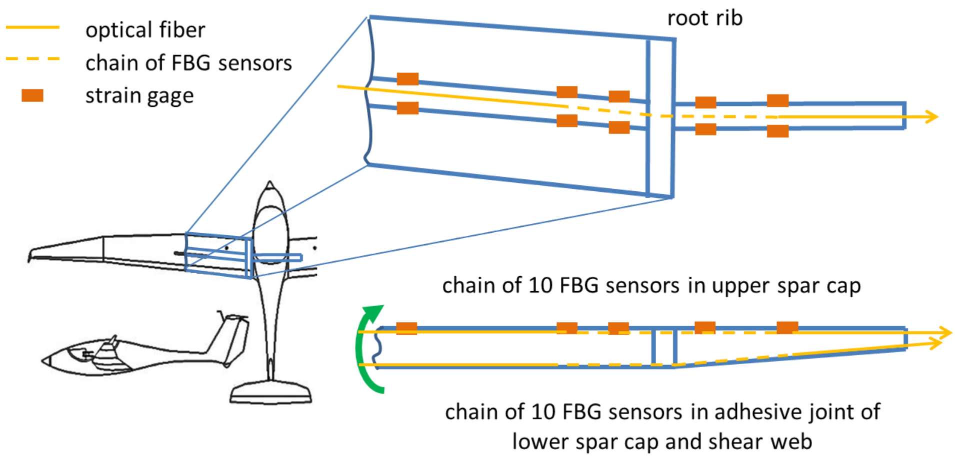

Fig. 2 Location of the FBG sensors and strain gages on the wing spar.

FBG Sensors. Optical fibers with FBG sensors were used to measure longitudinal strain during the experiment. Two optical fibers with multiple FBG sensors with following configuration were used; central Bragg wavelength: 825 - 870 nm (upper spar cap), 810 – 855 nm (lower spar cap), longitudinal/wavelength spacing between the successive FBGs: 50 mm/5 nm, grating length: 8 mm, outer diameter: 195 µm, coating material: ORMOCER®.

Strain Gages. Resistive strain gages were installed as a comparative method. In total, ten pieces of strain gages (HBM 1-LY11-6/350, length of measuring grid: 6 mm, nominal resistance: 350Ω) were installed using the HBM X60 two-component adhesive and HBM SG250 protective silicone rubber.

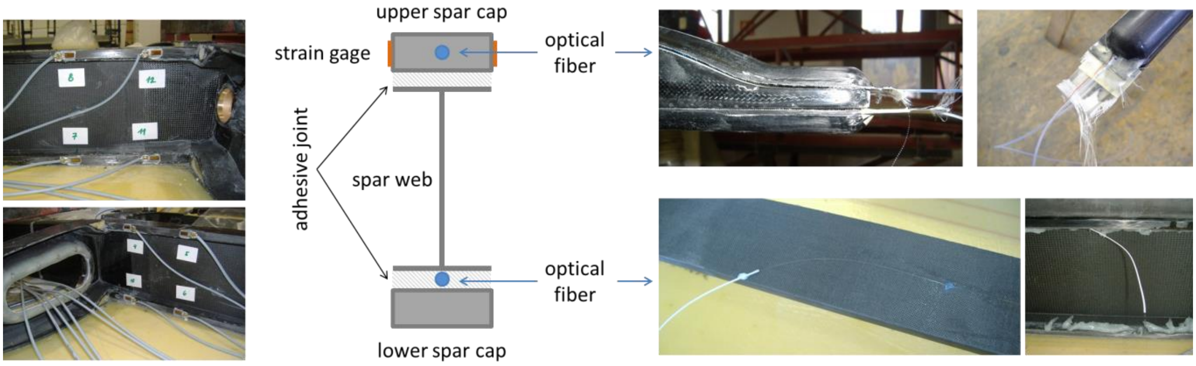

Fig. 3 Sensors placement scheme with details of ingress/egress points of optical fibers and strain gages cabling.

Places where the optical fiber enters into the composite structure are critical, with the maximum risk of optical fiber breakage. Optical fiber in the upper spar cap was taken out of the structure through the connecting hinge (see Fig. 3) and it was protected by the steel and Teflon tubes. Egress point from adhesive joint was made inside the wing, where the fiber is better protected against the handling damage. These connection types can be used even on production wing. Cabling for strain gages was made using the standard three-wire shielded cables. The obvious drawback is the relatively large mass of cables, in comparison with optical fibers.

Experimental Set-up

Load test of the wing was performed by the Institute of Aerospace Engineering from Brno University of Technology. The wing was placed in the fixture (in the flight position, see Fig. 4), which simulated influence of the second wing and the fuselage. Bending moment in a vertical plane was applied by hydraulic actuators (see Fig. 5), together with additional bending moment in horizontal axis (from trailing edge to leading edge). Data from the above-mentioned FBG sensors were captured using the Safibra FBGuard 4-channel optical interrogator. Strain gages were connected to the ESAM Traveller CF 32-channel data acquisition system, using the three-wire connection. Data signals were captured to PC units with frequency of 2 samples per second.

Fig. 4 Wing in the fixture.

Fig. 5 Configuration for bending load test.

Experimental Results and Discussion

Mechanical strain, measured by strain gages and FGB sensors, was used for calculation of stress in an upper and lower spar caps. Tensile modulus of carbon/epoxy caps was determined from specimens, which were made during the caps manufacturing process. Results were compared with data from simple analytical model of wing spar loads, for operational load level. Stress distribution is pictured in Fig. 6.

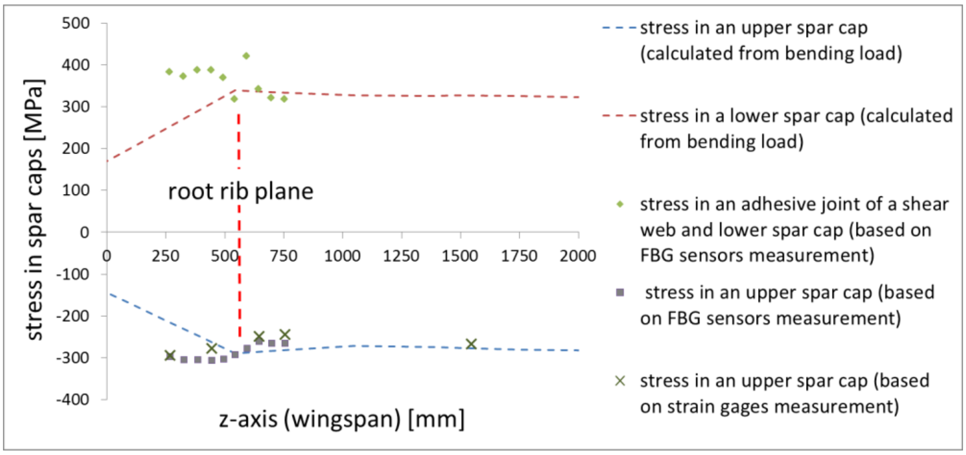

Fig. 6 Stress distribution in the spar caps over the wingspan (operational load level) .

Good agreement can be seen between analytical and experimental results. Difference in stresses in area of cantilever beam (0 – 545 mm) can be caused due to the following reasons:

- too stiff boundary conditions in a wing fixture, causing the additional load of a wing spar
- drop of shear force in area of cantilever beam, which is not considered in analytical model

Differences between the FBG chains in upper and lower spar caps are caused by their different location in the spar. While FBGs in the adhesive joint are directly influenced by shear forces in the shear web, FBGs embedded in the upper spar cap are protected.

Conclusions

Experiment confirmed the ability of integrated FBG sensors to survive production of the composite wing structure. Results from the first bending load test show good agreement between the data evaluated from measurements and a simple analytical model of wing load. Future work will be focused on a refinement of the analytical model, supported by experimental tests.

Acknowledgements

The authors would like to thank the Ministry of Industry and Trade of the Czech Republic for supporting this research with project no. FR-TI1/290.

References

[1] Boller Ch., Chang F.-K., Fujino Y., Encyclopedia of Structural Health Monitoring (Wiley, Chichester, 2009). ISBN 978-0-470-05822-0.

[2] E J Friebele, C G Askins, A B Bosse, A D Kersey, H J Patrick, W R Pogue, M A Putnam, W R Simon, F A Tasker, W S Vincent and S T Vohra, “Optical fiber sensors for spacecraft applications”, Smart Materials and Structures, vol. 8, pp. 813-838, 1999.

[3] Mancini S., Tumino G., Gaudenzi P., “Structural Health Monitoring for Future Space Vehicles”, Journal of Intelligent Material Systems and Structures 2006, vol. 17, pp. 577-585, 2006.

[4] Measures R.M., Structural Monitoring with Fiber Optic Technology (Academic Press, San Diego, 2001). ISBN 0-12-487430-4.

[5] Růžička, M. - Dvořák, M. - Doubrava, K.: Strain measurement with the Fiber Bragg Grating optical sensors. In Proceedings of the 50th Annual Conference on Experimental Stress Analysis. Praha: Czech Technical University in Prague, 2012, p. 385-392. ISBN 978-80-01-05060-6.