Development of Structural Health Monitoring System for Ultralight Aircraft

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Abstract: Development of Structural Health Monitoring (SHM) system based on a flight data acquisition device is described in the article. System consists of a fiber optic interrogation device, analog flight data sensors and optical Fiber Bragg Grating (FBG) sensors, which are embedded in main structural joints of wings and in stabilisers.

Keywords: FBG sensor; SHM; composite; aircraft; flight measurement.

1 Introduction

The main objective of our research is a development of system for monitoring of flight loads and flight parameters, such as speed, altitude, acceleration etc. Measured flight data will be then used for design of suitable SHM model for critical parts of airframe. Data acquisition device and related sensors are mounted in the Phoenix Air S-LSA Motorglider (see Fig. 1).

The airplane has all-composite construction, structural parts are bonded together using the epoxy adhesive. Adhesive joints are critical points of technology procedure. During the operation of wing skins assembly there is no direct control of bonded joint. Airframe damage during flight because of bad quality of bonding was observed in the past. Some of the manufacturers check quality of final assembly using the small cameras, but there is no method used for in-flight measurement of adhesive joints performance/health.

Fig. 1: Phoenix Air S-LSA Motorglider [1].

We have already shown earlier that FBG sensors embedded in the glued joints or carbon/epoxy spar caps are suitable for the monitoring of critical places of the wing structure during the torsional and bending stiffness tests [2, 3]. Results obtained from the FBG sensors were fully comparable to readings from the electrical strain gauges and were in good agreement with the results from analytical and numerical wing loads models. Moreover, it was shown in [4] that optical fibers in the glued joints don't lower the static shear strength or fatigue performance of such joint.

2 Description of the Monitoring System

In-flight data acquisition system consists of FBG interrogator Safibra FBGuard (modified to measure both optical and analog electric signals) and various sensors. System is designed to measure common flight loads, not taxiing or flutter loads, thus at least 5 Hz scanning frequency is required.

2.1 Sensors for the Strain Analysis of Airframe

The strain monitoring sensor system is based on chains of optical FBG sensors (multiple strain sensing areas on a single optical fiber). The following parts of the airplane are equipped with the sensors:

- *vertical stabiliser* (4 surface-mounted strain FBGs),
- *horizontal stabiliser* (4 embedded strain FBGs),
- *left wing* (26 embedded strain FBGs, 2 surface mounted temperature FBGs, conf. A),
- *right wing* (52 embedded strain FBGs, 4 surface mounted temperature FBGs, conf. A; 10 embedded strain FBGs, conf. B).

Configuration of the FBG sensors in the wings is schematically pictured in the Fig. 2 (top view). Positions of FBG chains inside the wing spar cross-section are pictured in the Fig. 3.

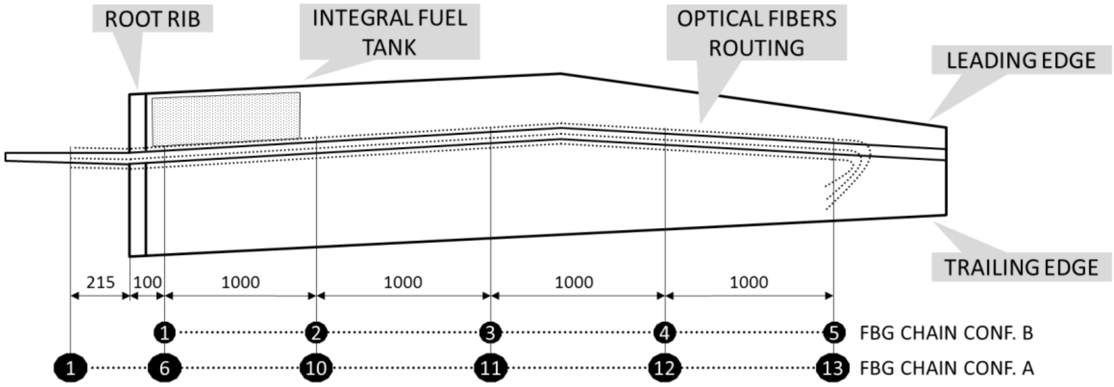

Fig. 2: FBG sensors configuration in the wing (top view).

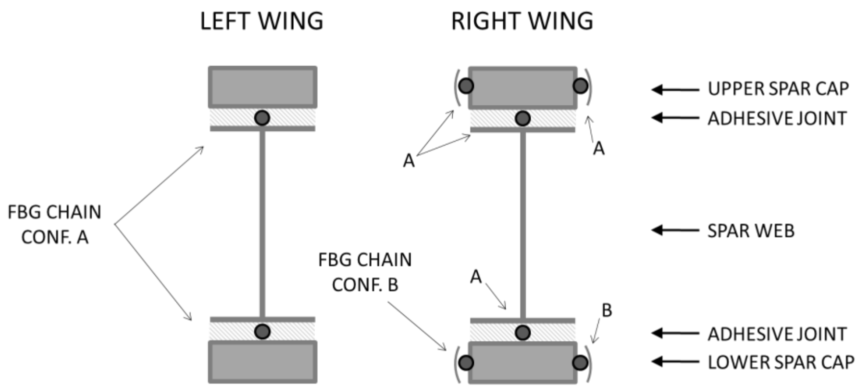

Fig. 3: FBG sensors configuration in the wing spars (cross-section).

Optical fibers, which were placed on the sides of the spar caps, were covered with the thin glass fabric for additional protection (see Fig. 3 – right wing spar cross-section). Optical fibers, which were embedded into the adhesive joints, were at first attached to the surface of the spar caps (using the fast curing adhesive, see Fig. 4) and then buried into the layer of epoxy adhesive. All optical fibers or cabling routes inside the wings were protected using the plastic tubes and boxes made from hard foam (to protect ingress points of the fibers, see Fig. 5).

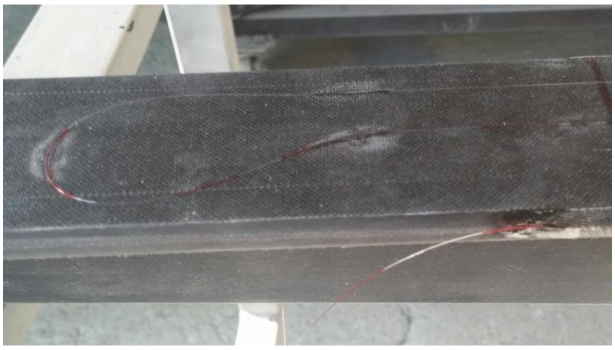

Fig. 4: Detail of optical fiber on the spar cap, just before application of epoxy adhesive.

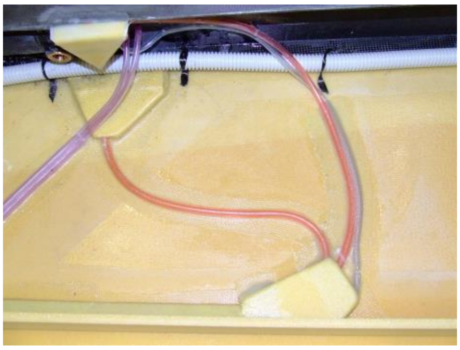

Fig. 5: Detail of protection of optical fibers and cablings inside the wing.

2.2 Sensors for the Measurement of Flight Parameters

Strain readings from the FBG sensors alone provide only partial amount of information about the airframe behavior during the service. Flight parameters such as acceleration, speed, deflection of control surfaces etc. are needed for detailed analysis of the flight conditions/loads. The following flight parameters are measured:

- *altitude* (absolute pressure sensor connected to a pitot-static system),
- *speed* (differential pressure sensor connected to the pitot-static system),
- *engine speed* (pulse counter and frequency to voltage converter connected to an ignition coil),
- *pressure in the engine intake* (absolute pressure sensor),
- *acceleration in the airplane center of gravity* (3-axis accelerometer),
- *acceleration in the empennage* (3-axis accelerometer),
- *deflection of ailerons* (linear/single-turn potentiometer),
- *deflection of an elevator* (linear/single-turn potentiometer),
- *deflection of a rudder* (linear/single-turn potentiometer),
- *deflection of flaps* (four positions, linear/single-turn potentiometer),
- *deflection of airbrakes* (linear/single-turn potentiometer).

2.3 Prototype of Flight Data Acquisition Device

The modified Safibra FBGuard 1550 FAST interrogation device was used as a basis for flight measurement system. It is equipped with 8 optical channels (250 Hz scanning frequency per channel) and 16 analog input channels (5-10 Hz per channel). All channels are synchronized.

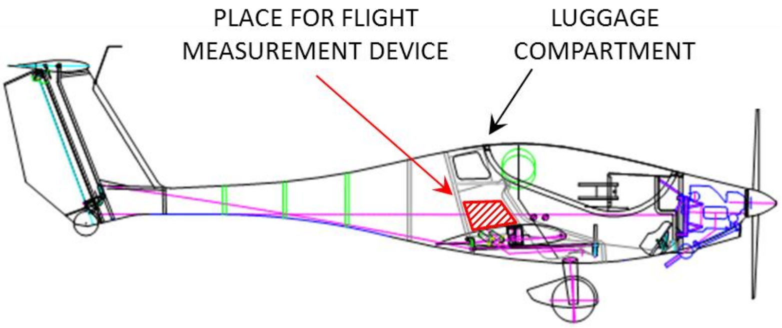

Fig. 6: Position of data acquisition device in the fuselage (side view).

Fig. 7: Detail of device inside the fuselage (behind the seats).

Device is placed under the luggage compartment (see Fig. 6) and it is fixed to structural parts of the fuselage (Fig. 7). Electric power supply is provided by the airplane electrical system. No connected PC is needed, measured data are stored inside the device.

3 Conclusion

Currently, the main parts of the system have passed laboratory tests and they are being installed into the airplane. Load time histories obtained from the flight measurements will be then used for finite element model refinement. In the next steps, local stress & strain histories will be derived from the model for the critical places. This will allow reduction of strain sensors, that are really needed for sufficient flight load measurement, also this will provide data for possible fatigue analysis of the bonded joints.

Acknowledgement

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References

[1] Retrieved from: http://www.phoenixairusa.com/

[2] M. Dvorak, M. Kabrt, M. Ruzicka, The use of Fiber Bragg Grating Sensors During the Static Load Test of a Composite Wing Structure. In Proceedings of the 51st Conference on Experimental Stress Analysis. Usti nad Labem: FVTM, UJEP, 2013, ISBN 978-80-7414-579-7.

[3] M. Dvorak, M. Ruzicka, M. Kabrt, Design of Embedded FBG Sensor System for Ultralight Aircraft Wing Monitoring. In Structural Health Monitoring 2015. Lancaster, Pennsylvania: DEStech Publications, Inc., 2015, p. 1665-1672. ISBN 978-1-60595-275-8.

[4] M. Dvorak, M. Ruzicka, Influence of Embedded Fiber Optic Sensor on Performance of Single-lap Bonded Joint. In 52nd conference on experimental stress analysis 2014. Research and Testing Institute Plzen, 2014, ISBN 978-80-231-0377-6.