Fiber optic strain sensor system for structural analysis of jet engine air intake

DVOŘÁK Milan[1,a], SCHMIDOVÁ Nikola[1,b], DOUBRAVA Karel[1,c] , VÁCLAVÍK Jan[2,d] and RŮŽIČKA Milan[1,e]

[1]Czech Technical University in Prague; Faculty of Mechanical Engineering; Technická 4, 160 00 Prague, Czech Republic

[2]AERO Vodochody AEROSPACE a.s.; U Letiště 374, 250 70 Odolena Voda , Czech Republic

[a]milan.dvorak@fs.cvut.cz, [b]nikola.schmidova@fs.cvut.cz, [c]karel.doubrava@fs.cvut.cz, [d]jan.vaclavik@aero.cz, milan.ruzicka@fs.cvut.cz

Keywords: Aircraft structure, Composite, Fiber Bragg Grating (FBG), Structural Health Monitoring (SHM), Fiber optic strain sensor

Abstract. This paper describes experimental verification of a fiber optic strain sensor system for a composite air intake. The new L-39NG jet trainer aircraft from Aero Vodochody is equipped with all-composite air intake. Because there is a need of its acoustic load analysis, both optical and electric strain sensors were installed to its surface. Engine ground test was performed to test fiber optic sensor system at first. It was found that the system is fully functional with capability to provide the required performance. Acquired data were used for further air intake design improvement.

Introduction

Our current work is focused on further development of an optical FBG (Fiber Bragg Grating) sensor system, which was designed to monitor behaviour of a composite air intake (Fig. 1, right) for the L-39NG light jet trainer (Fig. 1, left). Previous works were focused on a performance of the air intake demonstrator during the bird and hail impact tests [1, 2] and on the sensor system detection capability [3, 4]. It was proven that method of installation onto composite structure, which was developed previously, is durable and reliable even during the large energy impact detection testing. Now work has progressed to installation and measurement on the first prototype airplane.

Fig. 1: L-39NG light jet trainer (left) [5]; 3D model of composite ait intake [6]

Sensor System

Four optical fibers with total of forty FBG sensors were installed on the surface of the air intake to monitor its behavior during ground engine test run. Air intake consists of left and righ part, each part is instrumented using two optical fibers with custom-made chains of FBG sensors (6xFBG in the front, 14xFBG in the rear part of the air intake). Optical fibers with outer diameter of 0.150 mm and polyimide primary coating were attached to surface and covered using the thin layer of glass fabric and epoxy resin (see Fig. 2). Individual sensors are placed close to the strain gauges with orientation for the circumferential deformation measurement (in the rear part) or longitudinal deformation measurement (front part). Fiber optic routing on the left side of the air intake can be seen in the Fig. 3 (left). Cured and painted part of the air intake instrumented with strain gauges and FBG sensors (blue cabling) can be seen in Fig. 3 (right).

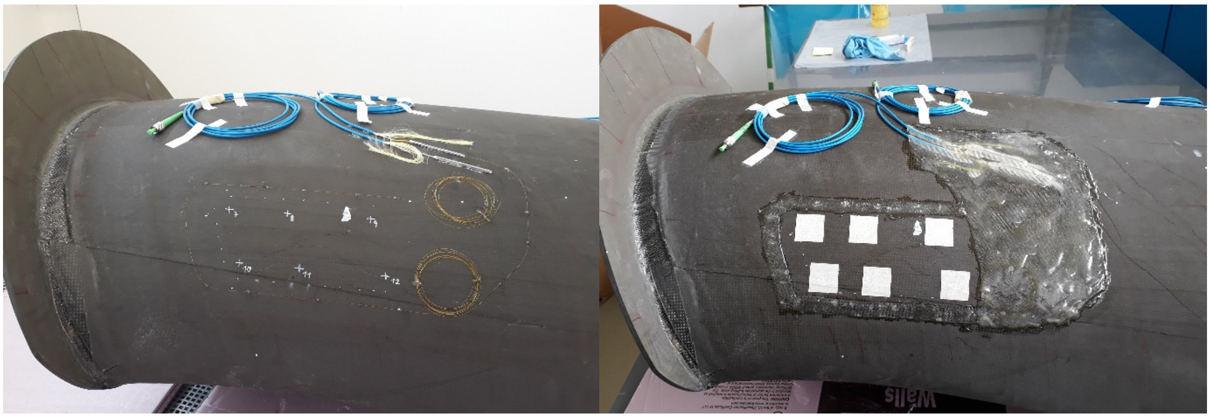

Fig. 2: Optical fiber with 6 FBG sensors attached to the air intake surface (left); optical fiber after lamination, before curing and painting (right)

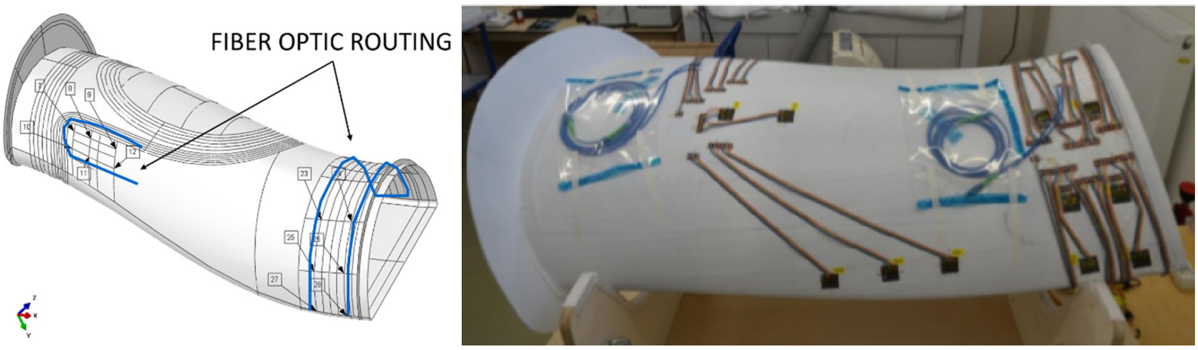

Fig. 3: Fiber optic routing on the left part of the air intake (left); air intake instrumented with strain gauges and FBG sensors (blue cabling)

Engine Ground Run

For the first ground test only FBG sensor system was used for strain measurement, mainly because fiber optic sensors are dielectric. Thus there is no risk of interference with any airplane system, moreover they're immune to interference induced by running engine and related airplane systems. Electric strain gauges will be also used for future testing. Because the main goal of a structural analysis was to monitor acoustic load from the running engine, the sensor system was primarily designed to measure small strain values (estimated strain amplitude about 50 μm/m) in combination with the requirement for a high sampling rate (first blade frequency is about 3.6 kHz). Mechanical strain over time measured during the engine ground test is shown in the Fig. 4. As can be seen, in addition to the expected high-frequency oscillation, the additional quasi-static deformation of the structure was measured, with amplitude ranging from about 90 µm/m (FBG03) on the sides of the structure to about 3100 µm/m in the bottom (FBG14) and top part. Further analysis showed that influence of an air suction during the maximal engine power on the ground (with the zero flight speed) was undervalued. So the air intake structure has deformed excessively in the place where the geometry is complicated (corner between the outer sidewall and the inner straight vertical wall) and where the air intake is connected to the surrounding fuselage structure.

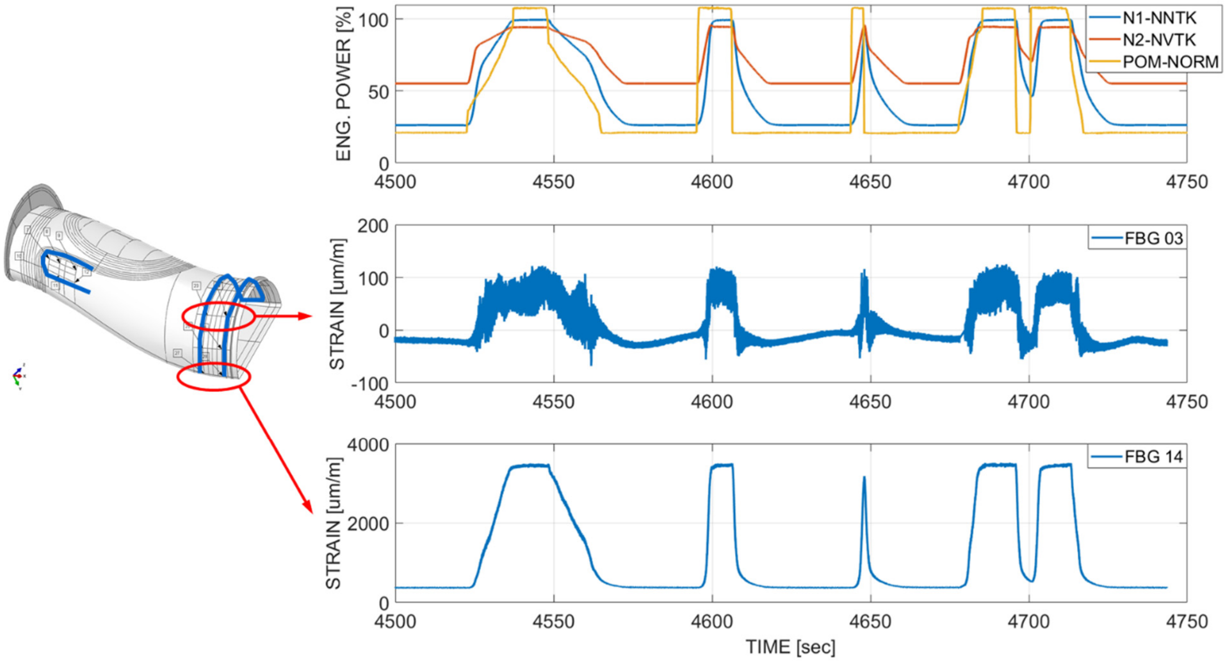

Fig. 4: Mechanical strain measured by the selected FBG sensors over time

Conclusions

First full-scale test of FBG sensor system for the air intake monitoring has shown that it is fully functional with capability to provide the required performance. Both high frequency strain values with small amplitude and quasi-static strain values with large amplitude were measured. No interference induced by the running jet engine or another aircraft system was observed. The measurement data were used to verify the design of the structure and as a basis for modifications.

Moreover, it has been confirmed that the developed procedure of installation and protecting of the optical sensor system allows further steps such as assembly of the air intake, its fitting into the fuselage and installation of the surrounding avionics without damaging the sensors.

The future experimental work will be focused on a comparison of both FBG sensors and electric strain gauges measurement systems during the following engine ground test. The obtained data will be used for further tuning of the finite element model of the air intake structure.

Acknowledgement

The authors would like to thank the Technology Agency of the Czech Republic for supporting this research with the project no. TE02000032.

References

[1] R. Doubrava, M. Oberthor, P. Bělský, M. Dvořák, K. Doubrava, Experimental Verification of Jet Engine Composite Inlet for Bird and Hail Stone Impact Resistance, In: EAN 2018 56th conference on experimental stress analysis, Conference Proceedings. Praha: Česká společnost pro mechaniku, 2018. p. 21-22. ISBN 978-80-270-4061-2.

[2] K. Doubrava, M. Dvořák, R. Doubrava, J. Václavík, M. Růžička, Experimental Analysis of Jet Engine Air Channel Impact Resistance by Means of Strain Gauges and FBG Sensors, In: EAN 2018 56th conference on experimental stress analysis, Conference Proceedings. Praha: Česká společnost pro mechaniku, 2018. p. 19-20. ISBN 978-80-270-4061-2.

[3] M. Dvořák, N. Schmidová, M. Kadlec, M. Růžička, Use of FBG Sensors for Delamination Growth Measurement under Mode I loading, In: 55th Conference on Experimental Stress Analysis 2017. Košice: Technical University of Kosice, 2017. p. 102-107. ISBN 978-80-553-3167-6.

[4] N. Schmidová, M. Dvořák, M. Kadlec, M. Růžička, Monitoring of Delamination Growth on the MMB Specimens Using FBG Sensors and Electrical Resistance Measurement Method, In: EAN 2018 56th conference on experimental stress analysis, Conference Proceedings. Praha: Česká společnost pro mechaniku, 2018. p. 367-373. ISBN 978-80-270-4062-9.

[5] M. Bartošák, J. Jurenka, V. Kulíšek, M. Růžička,Structural-Acoustic Analysis of Air Duct Using FEM, In: 33rd conference with international participation Computational Mechanics 2017 - Extended Abstracts. Pilsen: University of West Bohemia, 2017. p. 3-4. ISBN 978-80-261-0748-4.

[6] Retrieved April 30, 2019, from http://www.aero.cz/