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FATIGUE TEST OF COMPOSITE WING SPAR WITH USE OF THE FBG STRAIN GAGES

Abstract: The paper presents experimental and numerical investigation of wing's spar. Part of the spar was subjected to one step fatigue test, covering 10,000 load cycles corresponding to the oscillations of the load factor from $n_{z\ min}$ =- 3.7 to $n_{z\ max}$ = 5.7. Such test is proposed as an alternative to the full loading spectrum tests. Application of optical strain gauges based on a fiber Bragg's grating allowed to observe the phenomenon of local, periodical strengthening of the structure.

1. Introduction

The production started of new motor glider type requires fatigue tests to prove real fatigue life of such structure. Modern constructions of composite gliders and motor gliders should fulfil minimum of 9,000 flight hours. It gives the possibility of more than two decades of service at the annual statistics of the average user flying time. Such conditions have been the subject of our research work [1, 3,4,5]. Safe life of composite thin-walled structure means that operating loads in time of service do not cause such weakness of the structure, which violates the applicable safety factor (the ratio of loads to the destructive limit loads). For all aircraft structures, this factor has a value of 1.5. The remained strength at the end using of such structure cannot be less than 150% of allowable loads.

Evidence of fatigue life can be carried out by the fatigue tests. Fatigue testing programs are associated with the various features of the fatigue properties of composite structures. Fiber-reinforced composites feature is that it is insensitive to variable loads with low values, but their fatigue life and remained strength is significantly reduced as a result of single loads closed to the lower limit of scatter of immediate strength.

The above-mentioned properties of composites mean that instead of expensive whole motor glider bench studies could be more economical to show the fatigue life of some parts of the airframe structure. Rational will be to divide the fatigue test of a composite structure to the following steps: studies of force introduction nodes; studies of most loaded structure element – wing's spar, studies of wing-fuselage unit.

2. Loading and attachment conditions of tested spar

The main task during the preparation of experimental studies of actual structures is to ensure conditions of loading and attachment as accurately as possible similar to the working conditions of the element. The tested composite spar is installed in a motor glider fuselage by two fittings in its bayonet part.

During the motor glider's flight, as a result of pressure distribution on the surface of the wing appear forces, which are transmitted to the spar through the structure of the wing. Thus, spars works in a complex load state. Such conditions are extremely difficult to reproduce during fatigue testing, due to the need to control many parameters, which leads to a complex loading system.

For simplicity, it was decided to carry out a one-parameter fatigue test. For the wing spar is assumed that shear force is the most influencing load. This way, occurrence of the shear force and bending moment on the bayonet part was provided with values corresponding to real load of the structure (fig.1).

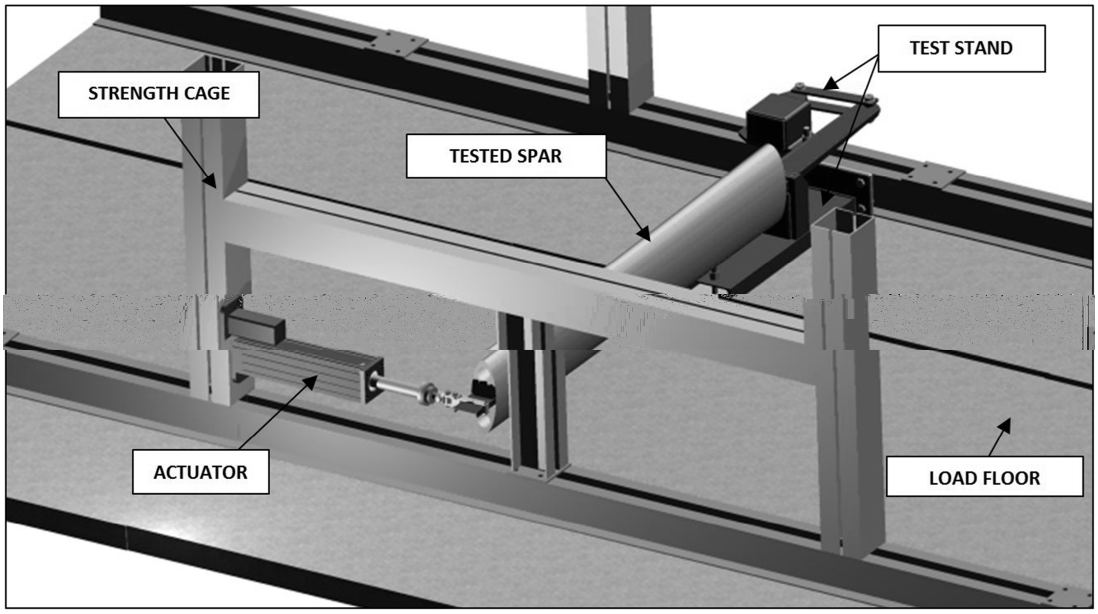

Fig.1 CAD model of test stand

3. Load spectrum

The test spar was subjected to one step load spectrum, what avoids the need for long-lasting and expensive research on the full, operational spectrum.

During the test, the power was generated by electro-mechanical Zwick-Roell cylinder, with force level control. Figure 2 shows carried load spectrum. Cycle asymmetry factor was R= -0.65 which corresponds to changes in load factor in the range of n = 5.7 to n = - 3.7. Test program established to carry out 10,000 load cycles.

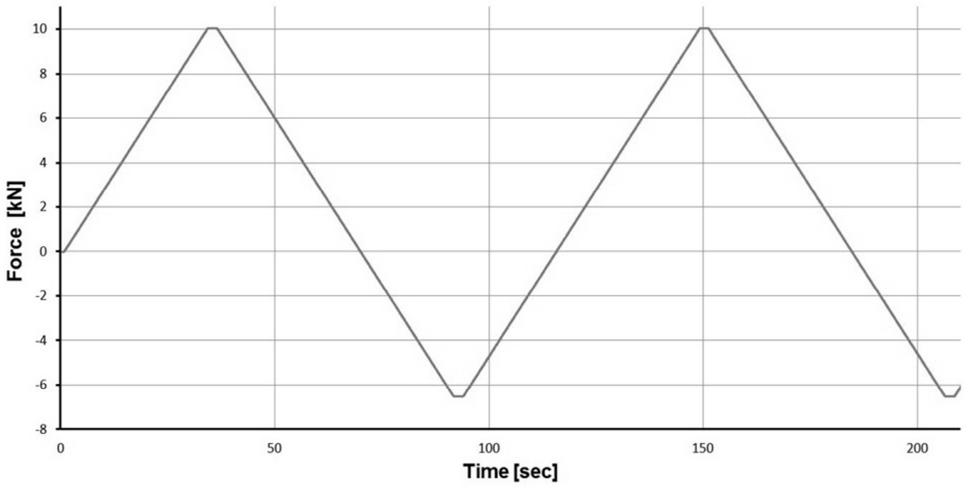

Fig.2 Load spectrum

4. Spar construction

Tested spar was a fully composite structure, constructed as an I-beam. The most sensitive area is called bracket's part of the spar and connects the wing to the fuselage. The remaining part is responsible for ensuring transfer of shear forces and bending moment from the wing to the fuselage.

Bayonet part has a sandwich structure. Core is made of polyurethane foam DIV-60 sandwiched between twenty-six layers of carbon fabric SGL KDK 8042. In the most loaded areas containing fittings, different layers were used. The whole structure was covered with one layer of glass fabric Interglas 92110. Spar flanges are made of unidirectional carbon composite (roving) Torayca T700G. Wall of the spar inside the wing creates a laminar structure with properly graded carbon fabrics (fig.3a).

Support points (force introduction on the composite structure) were made as a steel sleeve, forming the so-called labyrinth lock. A scheme of such structure was shown in figure 3b.

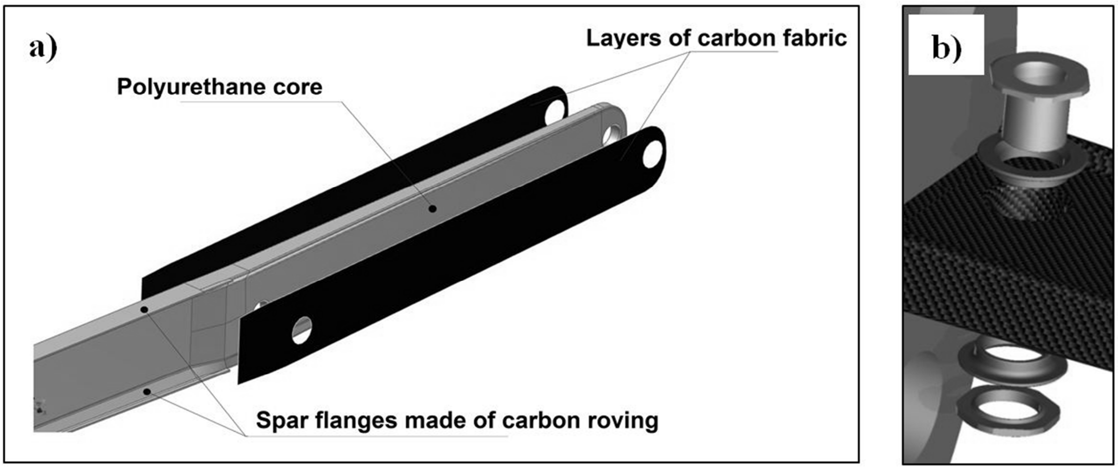

Fig.3 a) Scheme of composite structure
b) Construction of labyrinth lock

5. Optical strain gages

Experiments with composite spar became an opportunity to test optical strain gage based on fiber Bragg gratings, in conditions of sustained cyclic loading. Compared to the traditional measurement of deformation based on resistance strain gages, tested system presents many advantages, of which the foreground (in aerospace applications) extends its small mass. Reduced weight of such measurement system is linked to the possibility of placing up to 13 points on a single optic fiber.

The operation principle of optical strain gage is based on Bragg gratings, in the form of periodic cuts on fiber, with the task of reflecting a specific wavelength of light. The length of the applied grid is thereby the base of strain gage (in used sensors, it is about 6mm).

Signal in the form of a light wave is generated in the device called an interrogator (fig.4), which is also the receiver of the reflected light.. After reflection, the remainder of the light wave passes through the fiber remains and is used as a measuring signal for subsequent configuration of sensors with different notched grid [2].

Fig.4 Illustration of optical strain gage and interrogation device [HBM GmbH]

Measurement of deformations is realized by comparing the reflected light wave length changed by elongation or shortening of the sensor, to the reference wavelength of unstrained sensor.

During the researches, changes in strain near the front ferrule observed (fig. 5). The initial phase (up to 5,000 cycles) showed no significant changes in work of structure. Next load cycles (5,000 – 6,000) resulted the significant decrease in the measured strain, which can indicate the strengthening of the composite structure, associated with the setting of the carbon fibers in a matrix of epoxy resin. Then, over the 1,000 cycles indication returned to baseline.

The last phase of research showed the tendency to stiffening structure part with introduction point of concentrated forces. It should be noted, however, the fact that the construction in terms of macroscopic demonstrated no significant changes in stiffness, for example, a change that results in the deflection of the beam which demonstrate that the observed phenomenon is local.

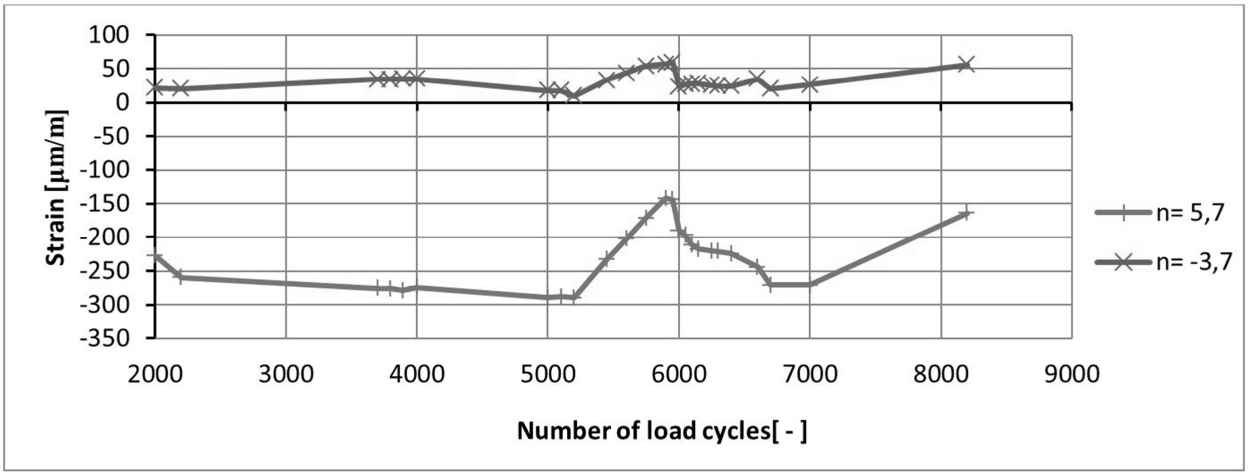

Fig. 5. Changing of strain during the test (strain gage no 1545)

6. Conclusion

It was realized full test program and significant changes as well in the composite parts as in the rigidity of the structure were not observed. It has been proved this way the aimed spar fatigue life. After end of test program, there were no fatigue damages of the spar. Composite parts in the area of primary fitting was subjected to detailed inspection, where also was not observed this kind of changes (fig.6).

First experience with the use of optical strain gages based on fiber Bragg gratings in fatigue tests of composite structures, with high levels of strain, confirm the usability of this type of measurement system. Application of such strain gages allowed to observe the phenomenon of local, periodical strengthening of the structure during the experiment.

Results of fatigue test presented in this paper did not finish the intended research. The presented spar will be subjected to further load cycles, which will lead to the determination of the limited cycle-numbers corresponded to the actual safe life time of tested composite structure.

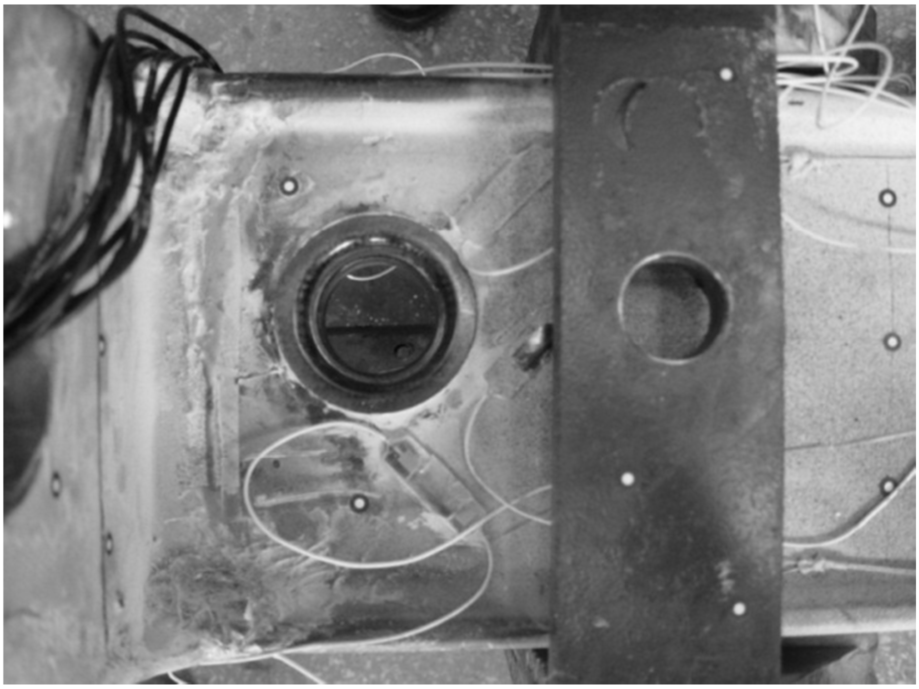

Fig.6. Structure state after test program

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