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Marek ORKISZ
Łukasz ŚWIĘCH
Jan ZACHARZEWSKI

FATIGUE TESTS OF MOTOR GLIDER WING'S COMPOSITE SPAR

BADANIA ZMĘCZENIOWE KOMPOZYTOWEGO DŹWIGARA SKRZYDŁA MOTOSZYBOWCA

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 nz min = −3.7 to nz max = 5.7. Such test is proposed as an alternative to the full loading spectrum tests. During the experiment 3D scan was used to rapid inspection of sensitive structure's areas. Application of optical strain gauges based on a fiber Bragg's grating allowed to observe the phenomenon of local, periodical strengthening of the structure.

Keywords*: composite structures, fatigue tests, FBG strain gages, finite element method (FEM), 3D scanning.*

W pracy przedstawiono badania eksperymentalne i numeryczne dźwigara skrzydła. Fragment dźwigara poddano jednostopniowemu testowi zmęczeniowemu, obejmującemu 10.000 cykli obciążeń odpowiadających oscylacjom współczynnika obciążeń od nz min= −3.7 do nz max= 5.7. Test taki proponowany jest jako alternatywa dla próby z zastosowaniem pełnego spektrum obciążeń. W trakcie badań wykorzystano skanowanie przestrzenne, jako propozycję szybkiej metody inspekcji newralgicznych obszarów konstrukcji. Zastosowanie do pomiaru odkształceń systemu światłowodowych czujników tensometrycznych opartych na siatce Bragga'a pozwoliło na zaobserwowanie zjawiska lokalnego, okresowego umacniania struktury.

Słowa kluczowe*:struktury kompozytowe, badania zmęczeniowe, tensometry oparte o siatkę Bragg'a, metoda elementów skończonych (MES), skanowanie przestrzenne.*

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 fulfill 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 [1,2,3,5,6,7,8]. 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:

a. Studies of force introduction nodes;
b. Studies of most loaded structure element – wing's spar;
c. Studies of wing-fuselage unit.

2. Loadnig 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.

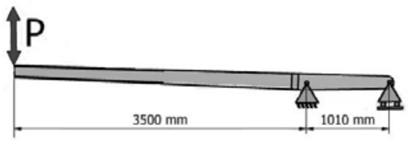

Fig. 1. Scheme of support and loading of spar

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

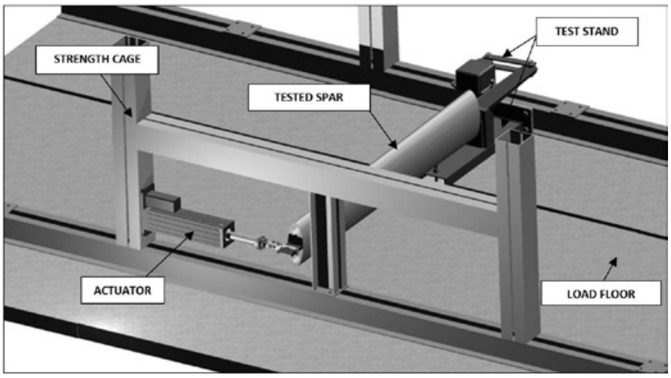

Fig. 2. CAD model of test stand

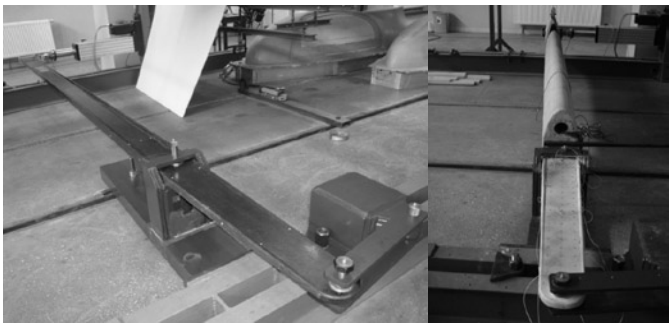

Fig. 3. General view oftest standwith attachedspar

Due to the dimensions of the spar (4.5 meters), CAD model of complete test stand with a part of the strength cage and load floor which are the place of attachment, was designed (fig.2).

In order to protect against the loss of stability of the spar, torsion box was made of glass-fiber reinforced composite intensified by wooden ribs. Torsion box task is to take over the torque, which was created by twisting of the spar.

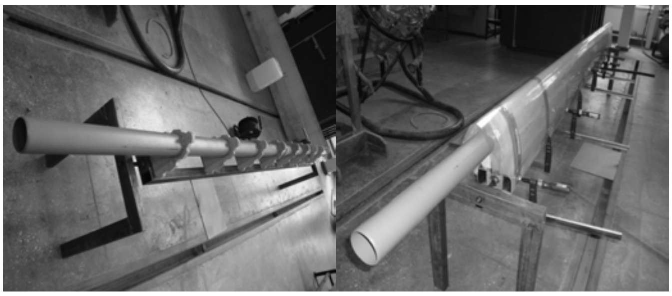

Fig. 4. Torsion box

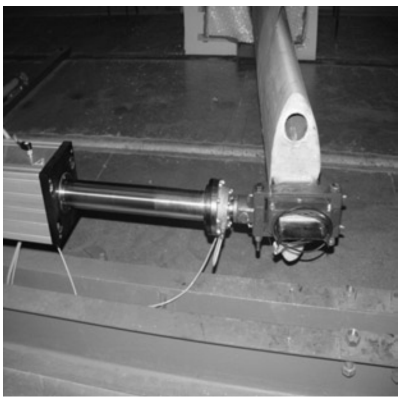

Fig. 5. Force introduction onspar

3. Load spectrum

Using the experience and the suggestions made in [1], 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 6 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 loadcycles.

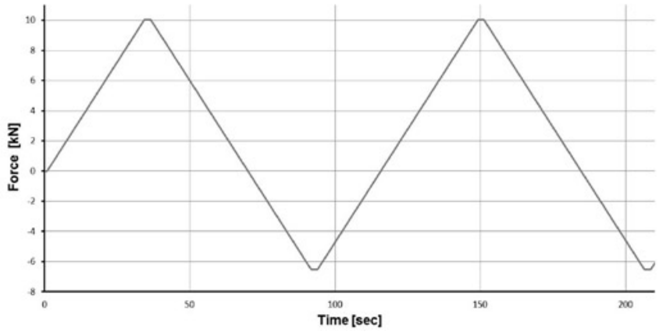

Fig. 6. Realized load spectrum

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.

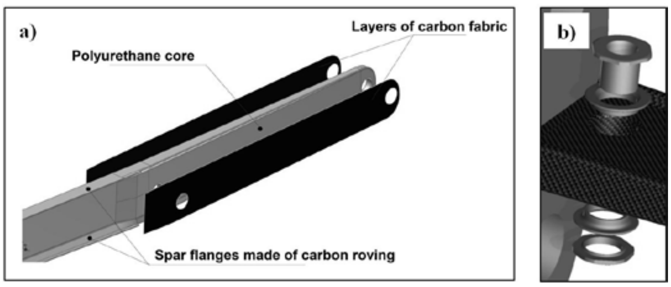

Fig. 7. a) Scheme of composite structures, b) Construction of the labyrinth-lock

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 7b.

The spar was designed and manufactured in the Aeronautical Department of Warsaw University of Technology.

5. Finite element analysis of spar

The aim of numerical analysiswasto complete thefatigue tests. This allowedto visualize fieldsof displacements andstressesinthe testedstructure. Calculationswere performedwith MSCNastran2010, usingproceduresof linearstatic analysis.

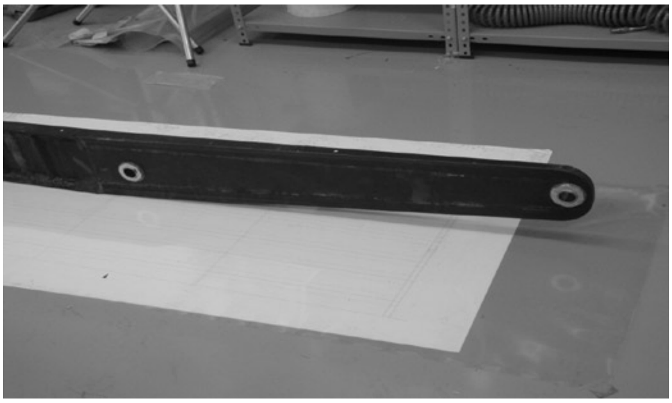

Fig. 8. Bayonet partof the testedspar

Fig. 9. Simplified geometry of thespar with support markers

On the basis ofthe detailedgeometry, simplifiedsolid model of spar was made (fig. 9), which was used to perform calculations.

Due to the complex spar construction (sweep and dihedral), it was decided to made the whole tested piece of the spar, what eliminated the necessity of applying loads as the internal forces. Method of attachment and load corresponds to the experimental conditions.

FEM model was built of both elements of 1D, 2D and 3D. Spar flanges and foam of the bayonet part were made of eight-node solid elements, with corresponding material properties, limited to isotropic, elastic model.Carbon fabric surrounding the core and the remainder of the wall sheathing simulate four-node plane elements, with orthotropic material model with definition of all laminate layers. In order to avoid troublesome phenomenon of contact, the steel fittings replaced with rigid 1D elements (fig. 10).

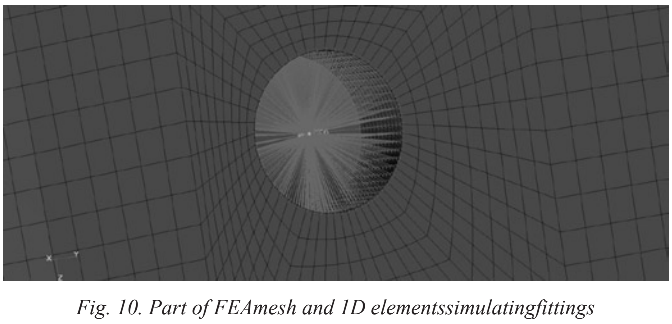

Fig. 10. Part of FEAmesh and 1D elementssimulatingfittings

Due to the low torsional rigidity of spar and to ensure one plane bending, it was taken the possibility of lateral movements of the elements forming the upper and lower spar flanges outside the bracket's part.

Load as during the experiment was carried out by applying shear force to the spar wall. There were performed two series of numerical analysis, corresponding to load factor

n = 5.7 and n = −3.7.

6. Measurement of spar deflection on bracket's part

Fatigue damage can be manifested through unstiffening of composite structure during the operation (tests). Easily measurable parameter of proving the change of stiffness of the structure, is to measure the deflection line of spar bracket's part. During the fatigue test, measurements of deflection between spar supports were made with use of inductive sensor. Data recording was made by using of HBM's acquisition system Spider8.

Fig. 11. Attachment ofthe inductive sensor

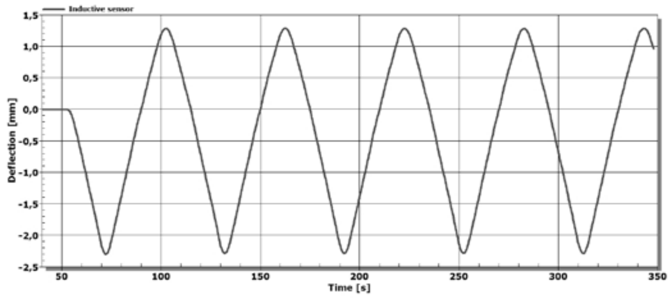

Fig. 12. Samplespardeflections

The size of deflections recorded by the inductive sensor are in the range from −2.3 mm for load n = 5.7 to 1.3 mm for load n = −3.7. Almost identical results were obtained in the FEM analysis (figure 13 and figure 14).

During program realization there was not noticed the change of the value of deflection, which shows no change in stiffness of the tested structure (fig. 15).

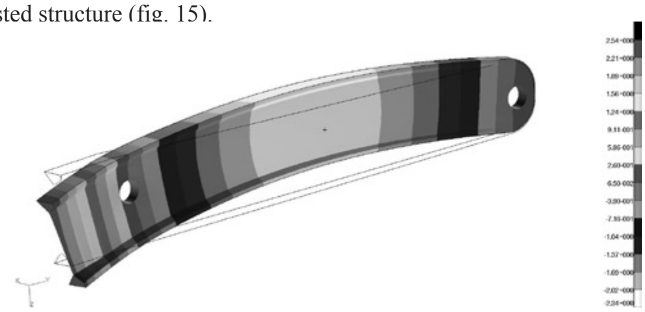

Fig. 13. Spar deflection. Result ofFEM analysis. Loadn=5.7

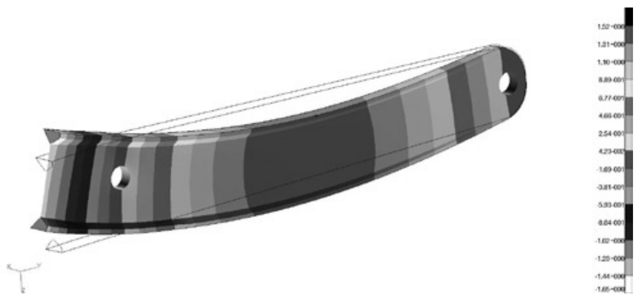

Fig. 14. Spar deflection. Result ofFEM analysis. Loadn=−3.7

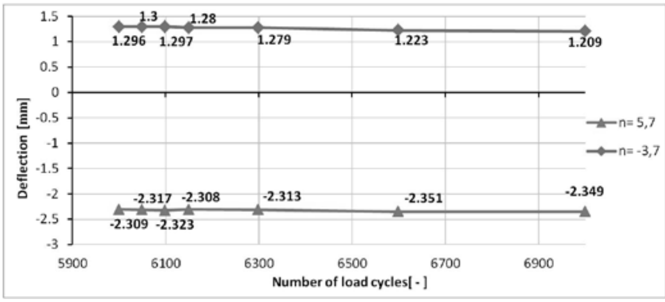

Fig. 15. Changes of deflection during the test

7. Measurement of fitting displacements

Force introduction nodes, caused high levels of stress in acomposite structure in area of fittings (fig.16), which creates arisk of irreversible deformations. One of the alarming symptoms of the possibility of these phenomena is the change of distance between mentioned nodes.

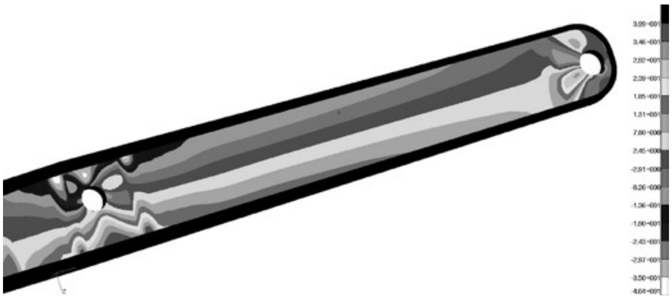

Fig. 16. Stressesin thebayonet part of spar

For measuring the displacement of nodes was used the optical white light scanner ATOS. It allowed three-dimensional digitization of the object, using the shadow moiré method and stereoscopic photography. With applied measuring field the accuracy of 0.01 mm was obtained. Inspections were made after the completion of each 1,000 load cycles.

Fig. 17. ATOS scanner

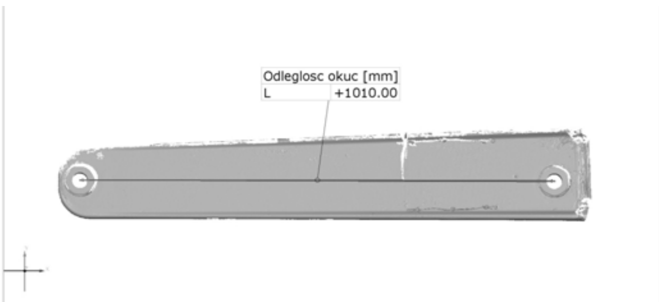

Fig. 18. Spar scanafter2,000load cycles

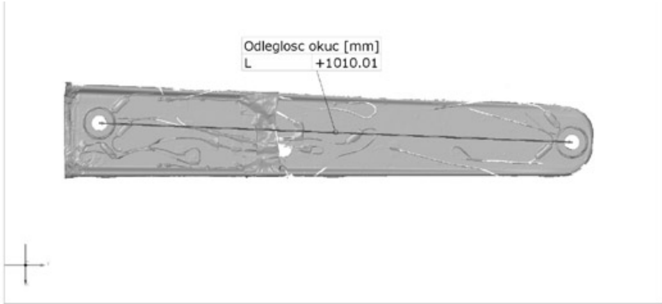

Fig. 19. Spar scanafter5,000load cycles

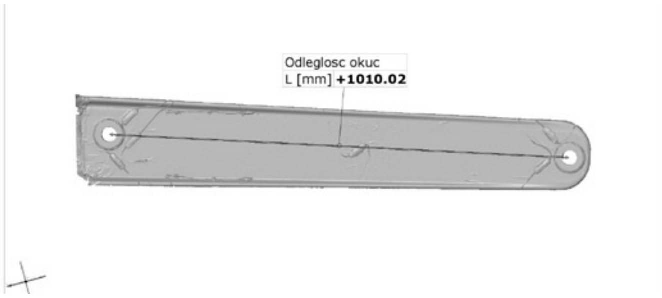

Fig. 20. Spar scanafter10,000load cycles

Inserted images show that the distance between nodes did not change significantly after 10,000 load cycles.

8. 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 fiber optic fiber [4].

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

Fig. 21. Illustration of optical strain gage [HBM GmbH]

the base of strain gage (in used sensors, it is about 6 mm).

Signal in the form of a light wave is generated in the device called an interrogator, which is also the receiver of the reflected light.. After reflection, the remainder of the light wave passes through the fiber remains (fig. 22) and is used as a measuring signal for subsequent configuration of sensors with different notched grid.

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. 24). 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

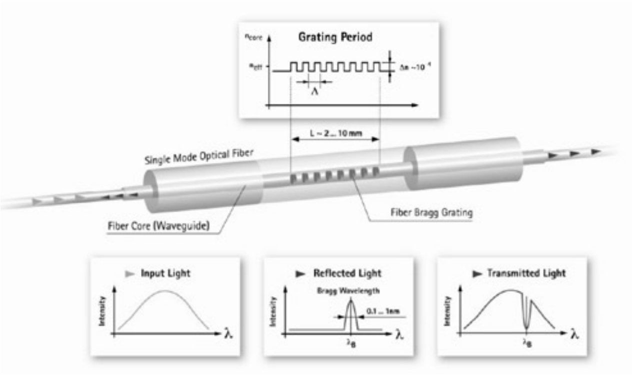

Fig. 22. Principle of Bragg gratings [HBM GmbH]

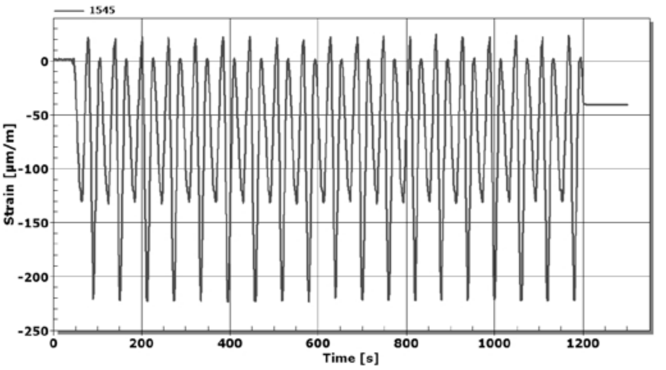

Fig. 23. Example of thestrainhistory ofstrain gagenumber1545(around the frontfitting) -6401-6450cycle

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.

9. Inspection of node's geometry

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. 25).

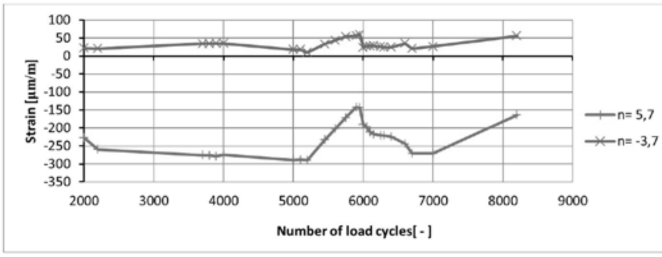

Fig. 24. Changing ofstrainduring the test(strain gage number.1545)

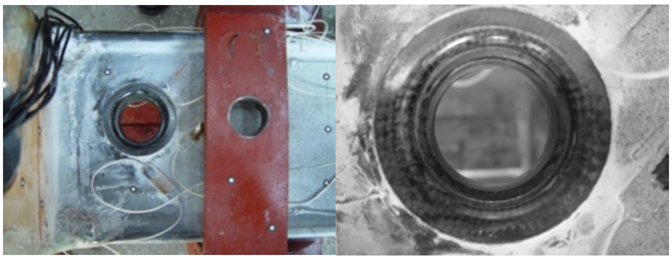

Fig. 25. Structure state after test program

10.Conclusions

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.

Reconstruction of studied structures surfaces using 3D scanning avoids the need to carry special equipment, which provides to perform accurate and simple measurements.

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.

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Professor Marek ORKISZ, Ph.D., D.Sc. (Eng.)
Łukasz ŚWIĘCH M.Sc. (Eng.)
Jan ZACHARZEWSKI, Ph.D. (Eng.)
Deptartment of Aircraft and Aircraft Engines
Rzeszow University of Technology
al. Powstańców Warszawy 8, 35-959 Rzeszów
e-mail: mareko@prz.edu.pl, lukasz.swiech@gmail.com, jzacharz@prz.rzeszow.pl