ISSN 2278-3091
Volume 8, No.5, September - October 2019
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse109852019.pdf
https://doi.org/10.30534/ijatcse/2019/109852019

Algorithm for assessing the technical condition of Aircraft structures using a Control System on Fiber Optic Sensors

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ABSTRACT

The paper presents a developed algorithm for assessing the technical condition of aircraft structures, including those made of composite materials, using a monitoring system on fiber-optic sensors, which allows tracking deformations and recording impacts.

Key words: Technical control, resource, fiber-optic sensors, polymer composite materials, impact damage.

1.INTRODUCTION

Most modern aviation equipment is currently operated on a designated resource with a specified service interval and regulated procedures for writing off a resource, depending on the conditions and number of flights. For example, the operation of helicopter equipment occurs with a regular violation of the regulated operating conditions, as well as without regular checks of the current state, limited to visual inspection. With this approach to operation, standard methods for writing off a resource are not the optimal approach to assessing their condition. In recent years, the approach to the operation of aircraft in the current state [1] has become increasingly popular, the implementation of which requires the development of both technical condition monitoring systems, including the further development of technologies such as HUMS [2], and the introduction of new methods for assessing technical condition based on a large array of data from sensors embedded in the structure or installed on its surface.

Over the past two decades, polymer composite materials (PCM) have become widely used in aircraft structures. However, despite the obvious advantages in terms of simplifying the design of aircraft, the operation of PCM in aviation is associated with a number of difficulties caused by their layered structure and the difficulty of estimating the residual life. For example, a typical defect in PCM designs is internal delamination caused by impact, which may not appear externally, but can lead to serious consequences if it is not detected in a timely manner. Therefore, the relevance of applying systems for assessing the technical condition according to the current sensor readings and their history for PCM structures is an even more urgent task.

Currently, control systems are quite widespread in relation to helicopter technology, in which the diagnostics of particularly relevant units are based on the use of systems such as HUMS (Health and Usage Monitoring System) based on vibration monitoring [2]. They are mainly used to assess the condition of the engine, transmission. Moreover, this technology does not allow assessing the stress-strain state of structures in operation or registering impact parameters, which is necessary in the case of PCM structures.

One of the most promising technologies for the implementation of control systems is fiber-optic sensors [3], due to the following advantages: 1. lack of electromagnetic sensitivity, 2. small size, 3. high sensitivity to the measured value, 3. no restrictions on the length of the fiber optical cable. Due to its advantages, fiber-optic sensors can be installed both on the surface of structures and embedded between PCM layers at the stage of fabrication of a structure with the aim of subsequent monitoring of its technical condition in operation [1]. In addition, using various physical principles of data recording, fiber-optic sensors can be used to monitor a wide range of various parameters of external influence, including: deformation, temperature, shock, vibration, acoustic emission, etc. [4].

The aviation industry is one of the most conservative in terms of introducing innovations, including in connection with the high responsibility for people's lives. Therefore, the creation of a control system is not only a complex engineering task, but also a methodological one. The development of a system as a tool for measuring the parameters of external influences is the first step towards the implementation of systems for assessing the state of aircraft structures and operation at current conditions.

The creation of a technical condition monitoring system should also be accompanied by the development of a methodology for assessing the technical condition and residual life based on current data from sensors built into the design.

This article describes the developed methodology for assessing the technical condition of composite structures and residual life based on data from fiber-optic strain gauges and acoustic signals, which in turn can also be applied to metal structures without the need to determine the parameters of impact effects.

1.1 Description of the algorithm for assessing the technical condition of aircraft structures

The purpose of introducing sensors into the structure is to obtain comprehensive information about its condition during operation, including the registration of abnormal external influences such as shock or going beyond the level of operational loads on structural load-bearing elements. In addition, continuous monitoring of the state of deformation at critical points of the structure will allow a much more accurate assessment of the current damage to the structure than the procedure for its scheduled decommissioning.

Figure 1 shows an algorithm for assessing the technical condition of aircraft structures using data from strain gauges and acoustics. In this case, fiber-optic sensors are considered as the most promising from the point of view of the possibility of data acquisition on serial aircraft during operation.

The algorithm is divided into two main logical blocks: 1. Bench tests, 2. Operation. The bench test block briefly describes the standard procedure for determining the characteristic physic mechanical parameters of a structure, as well as the development of a finite element model of a structure that should be verified based on the results of bench tests.

During the operation of the structure, the technical condition monitoring system constantly monitors the loads / strains and records shock effects using fiber-optic sensors, which are analyzed to determine if excesses are allowed. If excess values are found, then a visual inspection and ultrasonic inspection of the structure is carried out to confirm damage to the structure. If no excesses are allowed, then the design is operated with the calculation and assessment of the residual life to the damage value D not exceeding the threshold, for example, D = 0.5. When accumulating over time and exceeding the threshold value of damage, during operation of the structure, ultrasonic monitoring is required and a further decision is made on the operation of the structure with the developer.

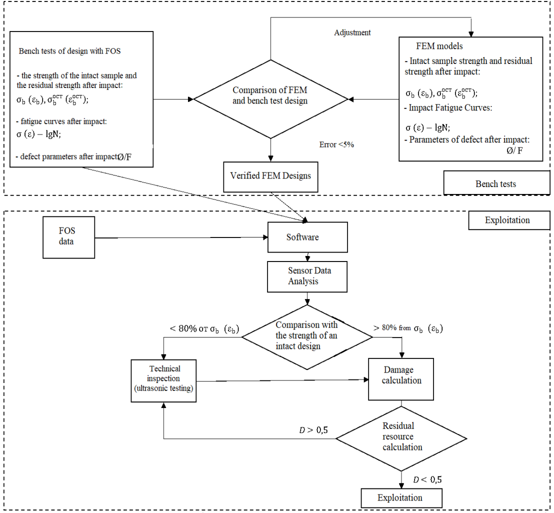


Figure 1: Algorithm for assessing the technical condition of aircraft structures using data from deformation and acoustics sensors

The presented algorithm is based on the damage accumulation hypothesis, which makes it possible to assess the durability of a structure based on the history of loading (changes in deformation or stresses over time) obtained using fiber-optic deformation sensors, after which the structure can withstand 80% of the breaking load (the value of the limit value of the load can be adjusted depending on the type of structure and its purpose). In this case, the calculation of the total damageability is determined by the ratio of the equivalent number of loading cycles of the structure for each of the loading units to the number of cycles sustained by the loaded object until the formation of a fatigue crack or to fatigue failure, which is determined during bench fatigue tests.

The equivalent number of load cycles of a structure is determined using the rain algorithm in accordance with GOST 25.101 83, GOST 23207 78 and reduction of cycles with different loading amplitudes to a zero stretching cycle by the Oding method.

The LS-DYNA program can be used as a CAD system to develop a finite element model of a structurally similar model from PCM. This program contains an extensive number of material models, including composite ones, with various fracture criteria, and is an advanced package for solving fast-moving dynamic problems, such as impact.

To detect shock effects on the controlled structure, it is possible to use fiber-optic acoustic sensors, which are also integrated with the fiber-optic strain gauges in the controlled structure. It is worth noting that for the calculation and refinement of the residual life of metal structures, it is also possible to use the developed methodology, adjusted for the absence of the need to register shock effects on the structure.

The developed evaluation algorithm was also tested on bench tests of structurally similar specimens with embedded fiber-optic strain gauges and acoustic, including shock and cyclic loading.

2.TESTING THE ALGORITHM

Bench tests were conducted to test this algorithm. A batch of composite samples, which are carbon fiber samples with an aluminum honeycomb core with integrated fiber optic sensors, was made (figure 2).

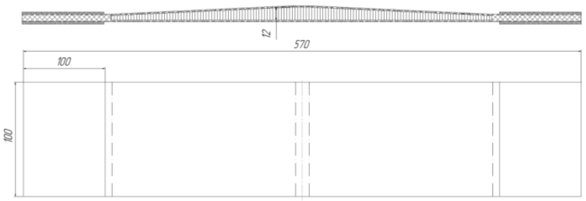
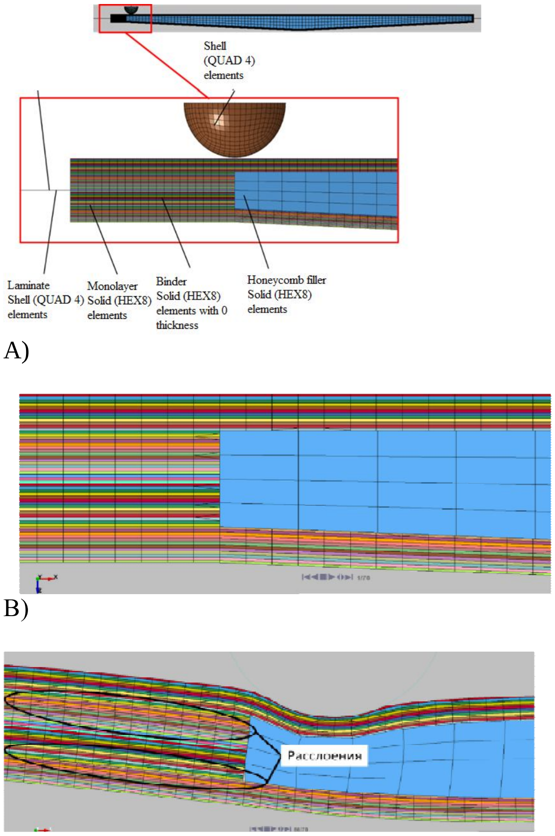


Figure 2: A carbon fiber sample with an aluminum honeycomb core with integrated fiber optic sensors

2.1. Preparation for testing the algorithm

In preparation for testing the algorithm, bench tests were carried out to determine the physical and mechanical properties of the samples, and a finite element model was also developed and verified (figures 3, 4). In particular, cyclic tests of samples after impact of various energies were carried out to determine the Weiler Curves. Solid-state 8-node elements are modeled for detailed simulation of the impact of a monolayer and a binder. The binder elements are “collapsed” solid-state elements with a “zero” height between the monolayer elements. The firing pin is modeled by shell elements. Monolayers are connected to the honeycomb via a TIED contact.



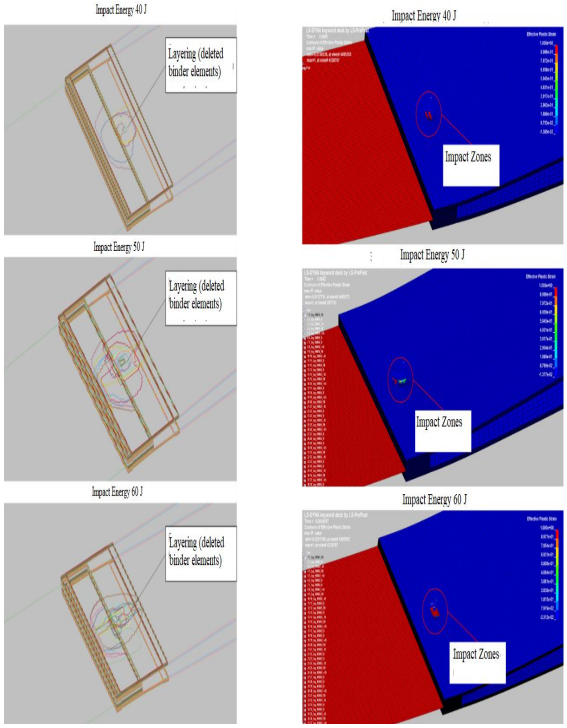
A)

B)

C)

Figure 3: Finite-element simulation of the impact process on a carbon fiber sample with a honeycomb core in LS Dyna software environment (A) - model of a striking impact, B) - model before impact, C - after impact)

In the course of mathematical modeling of the impact process, two types of defects are formed in the sample: delamination, implemented in the FEM finite element model in the form of removal of the binder material (cohesive elements) (Fig. 4A) and a decrease in the strength characteristics of the monolayer from impact (Fig. 4B).



A B

Figure 4: FEM analysis
A - delamination, B - degradation (loss of strength) of the monolayer

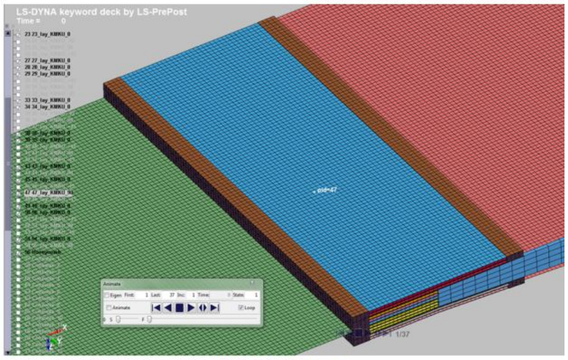
To determine the linear dimensions and the area of delamination in the sample, the dimensions of the defect in each of the layers of the binder were determined.

An experimental study of the impact was carried out on samples with impact energies of 40, 50, and 60 J. Ultrasonic testing was carried out with the determination of the separation parameters, and the location and impact energy were determined using fiber-optic acoustic sensors. Based on experimental data, FEM shock impact was verified.

After impact, the specimen undergoes a static load - stretching.

Figure 5 shows the FEM of the process of destruction of a 40 J sample damaged with impact energy.

Starting position



Final position

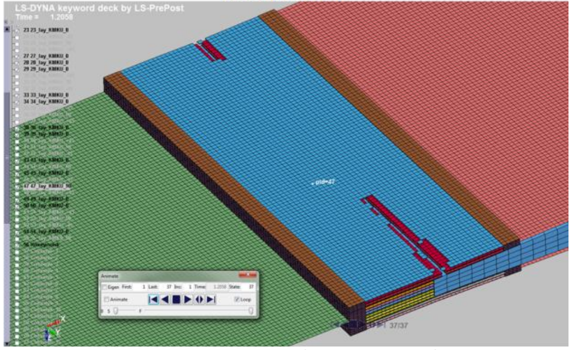
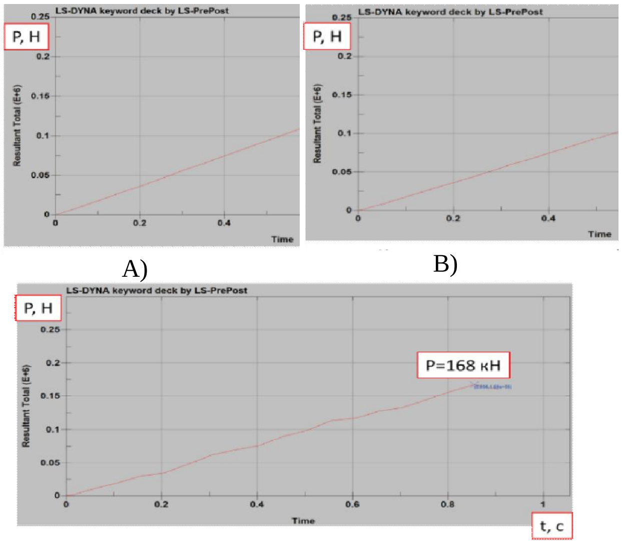


Figure 5: FEM, the process of destruction of the sample

Figure 6 shows diagrams of the breaking load of a sample at various impact energies.



A) B)

C)

Figure 6: FEM calculation results of the ultimate load of the sample at various impact energies (A) - impact with an energy of 40 J, B) - impact with an energy of 50 J, C) - impact with an energy of 60 J)

An experimental study of the sample under static tension after impact was carried out on a MTS hydraulic testing machine. The sample was installed in a testing machine, clamped in the area of the pads with a hydraulic clamp and stretched to failure with fixation of critical parameters. Based on the experimental data, the FEM of the tensile test specimen after impact was verified.

A number of impacted samples were tested for fatigue strength to obtain Weller curves.

2.2. Testing samples to test the algorithm

The methodology for testing carbon fiber samples with an aluminum honeycomb core with built-in fiber optic sensors in order to test the algorithm was as follows:

1) Striking with arbitrary energy impact on the samples using a metal striker.
2) Registration of impact with the help of fiber-optic acoustic sensors built into the samples, with the determination of the location and energy of the impact using them.
3) Estimation of the residual strength (breaking load Psize) of the impacted samples using the FEM according to the data obtained from fiber-optic acoustic sensors.
4) Carrying out fatigue tests (zero cyclic tension) to damage of 0.5 with an amplitude and a loading frequency of 0.8 * P and 10 Hz, respectively, according to the parameters of the previously obtained Weller curves. At the same time, the load is recorded using fiber-optic strain gauges built into the samples.
5) Static loading of the samples to failure with the determination of the breaking load after cyclic tension to damage of 0.5.

During bench tests, deformations were recorded using fiber optic Bragg gratings and a measuring system with the following main characteristics: strain measurement range: ± 1% elongation; inaccuracy of measuring deformation parameters: no more than 2%; data sampling rate: up to 500 Hz.

To record the impact, a laboratory setup based on a two-wave laser scheme similar to [5] was used; Fabry-Perot intrafiber resonators similar to [6] were used as sensors. This system allows you to register vibro-acoustic signals in the range from 1 kHz to 250 kHz. The use of digital signal processing algorithms allows discriminating impact energies up to 10 J.

3. SAMPLE TEST RESULTS

During the testing of the algorithm, the following results were obtained:

1. The error in determining the location and energy of impact on samples using fiber-optic acoustic sensors was not more than 5%.
2. The error in determining the residual strength of samples using FEM from previously determined parameters of impact using fiber-optic acoustic sensors was not more than 20%.
3. After determining the residual strength of the samples during fatigue tests according to the parameters obtained previously from the Weller curves until damage of 0.5, damage to the monolayers was not detected.

4.CONCLUSION

The paper presents an algorithm for assessing the technical condition of aircraft structures, including those made of composite materials, using fiber-optic strain gauges and acoustics. It is clear that to ensure the implementation of the methodology, it is necessary to conduct thorough preparation and testing of structurally similar samples of the studied structures both in the field of static and residual strength, and in the field of fatigue strength using modern methods of mathematical modeling and processing of experimental data.

Moreover, the developed approach will allow in the future more accurately assessing the residual life of the structure and reducing the time and financial costs of its extension.

ACKNOWLEDGMENT

The authors are grateful to the Russian Ministry of Education and Science for co-financing a project to develop a system for recording stall phenomena on the rotor blades of a helicopter during flight and monitor the technical condition of the swashplate (agreement No. 14.579.21.0150, identification number RFMEFI57917X0150); the results included in this material were obtained in the framework of this project.

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