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USE OF INFORMATION TECHNOLOGIES IN THE PROBLEMS OF DEFECTOSCOPY OF MULTILAYER CONSTRUCTIONS

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Abstract. Purpose of the research is the development of measuring technologies for testing multi-layer structures made from composite materials. **The object of research** is computer models of objects and their images when applying thermal and optical testing methods. **The relevance and practical inportance** of the study is due to the extensive use of composite materials in high-tech areas, which are characterized by the active introduction of new materials and the lack of serial production. **The scientific novelty** of the research is that the evaluation of the testing results reliability is carried out at the stage of measuring technology development. To solve this problem, it was proposed to use the combination of experimental and calculated data obtained with the help of modern **methods of computer simulation** of a stress-strain state under different loading conditions. Taking into consideration the constructive and mechanical properties of a particular design makes it possible to ensure high reliability of the testing results. The results of computer modeling can be used for machine learning of intelligent nondestructive testing systems.

Keywords: information technologies; computer modeling; multilayer structure; composite materials; non-destructive testing; defectoscopy; interferometry; infrared testing

ВИКОРИСТАННЯ ІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ В ЗАДАЧАХ ДЕФЕКТОСКОПІЇ БАГАТОШАРОВИХ КОНСТРУКЦІЙ

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Анотація. Метою роботи є розвиток інформаційно-вимірювальних технологій контролю багатошарових конструкцій із композитних матеріалів. **Об'єкт дослідження** – комп'ютерні моделі об'єктів та їх зображень при застосуванні теплових та оптичних методів контролю. **Актуальність і практична значимість** дослідження обумовлені широким використанням композиційних матеріалів у високотехнологічних галузях, для яких характерні активне впровадження новітніх матеріалів та відсутність серійного виробництва. **Наукова новизна** роботи полягає у тому, що оцінка достовірності результатів контролю здійснюється на етапі проектування інформаційно-вимірювальної технології. Для вирішення поставленої задачі запропоновано на етапі проектування інформаційно-вимірювальної технології застосовувати комбіноване використання експериментальних і розрахункових даних, отриманих за допомогою сучасних **методів комп'ютерного моделювання** напружено-деформованого стану об'єктів контролю при різних умовах навантаження. Урахування конструктивних і фізико-механічних властивостей конкретної конструкції дозволяє забезпечити високу достовірність результатів контролю. Результати комп'ютерного моделювання можуть бути використані для машинного навчання інтелектуальних систем неруйнівного контролю.

Ключові слова: інформаційні технології; комп'ютерне моделювання; багатошарова конструкція; композитні матеріали; неруйнівний контроль; дефектоскопія; інтерферометрія; тепловий контроль

ИСПОЛЬЗОВАНИЕ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ В ЗАДАЧАХ ДЕФЕКТОСКОПИИ МНОГОСЛОЙНЫХ КОНСТРУКЦИЙ

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Аннотация. Целью работы является развитие информационно-измерительных технологий контроля многослойных конструкций из композитных материалов. **Объект исследования** – компьютерные модели объектов и их изображений при применении тепловых и оптических методов контроля. **Актуальность и практическая значимость** исследования обусловлены широким использованием композитных материалов в высокотехнологических областях, для которых характерны активное внедрение новейших материалов и отсутствие серийного производства. **Научная новизна** работы состоит в том, что оценка достоверности результатов контроля осуществляется на этапе проектирования информационно-измерительной технологии. Для решения поставленной задачи предложено на этапе проектирования информационно-измерительной технологии применять комбинированное использование экспериментальных и расчетных данных, полученных с помощью современных **методов компьютерного моделирования** напряженно-деформированного стана объектов контроля при разных условиях нагружения. Учет конструктивных и физико-механических свойств конкретной конструкции позволяет обеспечить высокую достоверность результатов контроля. Результаты компьютерного моделирования могут быть использованы для машинного обучения интеллектуальных систем неразрушающего контроля.

***Ключевые слова*:** информационные технологии; компьютерное моделирование; многослойная конструкция; композитные материалы; неразрушающий контроль; дефектоскопия; интерферометрия; тепловой контроль

Introduction

The development of domestic high-tech industries and the competitiveness of their products in world markets is impossible without the use of new materials and production technologies. In turn, this leads to the need to create new measuring technologies that ensure compliance of products with the requirements of international quality standards. The problem of quality assurance in the aerospace industry is particularly relevant considering the increased safety and reliability requirements of products and significant economic losses in the event of destruction of a defective structure. In addition, in these industries, composite materials are actively used, the characteristic of which is the increased strength while reducing the total weight. But the peculiarity of such materials is the complexity of ensuring the stability of the physics-mechanical characteristics of the material and the technologies of their production, as well as the impossibility of using traditional statistical methods for evaluating the control data due to the uniqueness of the products and the lack of serial production. Thus, there is a problem of the creation and introduction into the production process of information-measuring technologies, which will allow the most reliable assessment of responsible physical and mechanical parameters and properties of materials, nodes and parts at all stages of product manufacturing.

An analysis of the current state of problem solving

A detailed analysis of technological defects arising in the manufacture of aircraft structures and products of rocket and space technology from polymer composite materials is given in works [3, 4]. Methods of mathematical modeling are actively used to study the processes of deformation and the influence of defects on the performance of nodes and aggregates of aero-space structures [2, 4].

The basic methods by which the testing of products is carried out are recommended by the standard ASTM E2533 - 09 [6]. It defines as the main methods of non-destructive testing in the aero-space industry the following methods: acoustic emission, ultrasonic testing, computer tomography**,** thermography, radiographic methods (radiography, digital and computer radiography, radioscopy), optical methods (shearography, visual testing). Each of these methods has its advantages and limitations. In particular, the acoustic emission does not allow to detect "inactive" defects, that is, those that do not develop. Radiation methods require access from both sides of the tested object. Acoustic methods, due to the considerable extinction of mechanical vibrations, can not be used, for the most part, to test structures manufactured using carbon fiber plastics. In addition, the difference between the surface of the tested object and the plane may be a significant limitation.

The greatest complication when using acoustic and infrared testing methods is the need to pre-adjust the devices on the control samples. This requires the full compliance of the physical and mechanical properties of the control sample and the product being controlled. Such disadvantages are deprived of methods of optical interferometry (shearography, speckle-interferometry, holographic interferometry). This led to the active development of measuring technologies and the creation of multiple devices that implement these methods.

It should be noted that despite the presence of sufficient number of proposals in the market of devices for interferometric testing, measuring technologies for specific products should be developed taking into consideration the peculiarities of their design and manufacturing technology.

One of the most common types of designs for the creation of aero-space products is multilayered composite structures. Thus, the problem arises of creating highly informative measuring technologies for their testing, ensuring the high reliability of the results.

Description of the research

To solve the problem, it is proposed to analyze the impact of the testing type, the size and location of defects on the testing results before the start of the creation of the measuring technology itself using computer simulation of the deformed state of the object.

For simulation of composite structures and analysis of their behavior, CAE systems MSC.Patran-Nastran, ANSYS, SolidWorks [1] are most commonly used. In this paper, SolidWorks software simulation was carried out to analyze deformation process under the action of the most common types of loading of objects during non-destructive testing, namely heating by infra-red radiation, vibration load and vacuuming.

As a tested object, a multi-layered structure was chosen, which was a glued plate of 10 layers of Getinax sized 180x80 mm^2 each with a thickness of 0,6 mm with "non-adhesive" defects between the layers. In the design model, 10 defects of square shape were modeled, with half of them having an area of 20x20 mm^2, while others - 10x10 mm^2. The defects were placed between contiguous layers of the plate in the upper part in pairs so as not to overlap each other, with defects number 9 and number 10 between the two upper layers (Fig. 1).

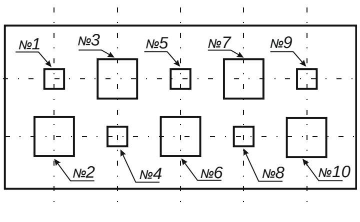

Fig. 1. Diagram of the defects location in a model

To evaluate the informativity of the testing results and compare the efficiency of different types of loads, simulation of structure deformations, which arise under the influence of infrared radiation, vibration load and vacuuming, was carried out.

Infrared testing is one of the most common types of non-destructive testing of multilayer structures. Fig. 2 shows the calculated thermogram of the model described in the multilayer design with infrared load.

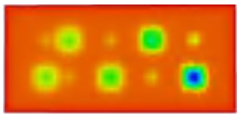

Fig.2 Thermogram of the surface of the tested object in the presence of “non-adhesive” between layers

It should be noted that the result of infrared testing for multi-layered structures depends to a large extent on the thermal resistance in the location of dyslamination, therefore, usually for the responsible parts, in addition to infrared testing, optical interferometry testing methods are used. In this case, the load of the object is carried out, using, as a rule, infrared radiation, vibration and vacuuming.

An important stage in the development of measuring technology for interferometric testing of multilayer structures is the creation of the calculated interference portraits of the tested object. The conclusion on the presence of a defect in the tested object and its location can be made by the presence of abnormal zones on the object surface image, which are closed systems of interference fringes, configuration and density of which depend on the shape, size and depth of the defect location.

The main informative parameter for the methods of optical interferometry, which makes it possible to give a quantitative estimate of the stress state of the tested object, is the value of the displacements of the object surface points due to deformation, which leads to a change in the phase of the wave front and the formation of interference fringes. In the SolidWorks software environment, it is possible not only see the qualitative picture of the deformation, but also to determine the value of displacement for an arbitrary point of the object surface for a given load level (Fig. 3).

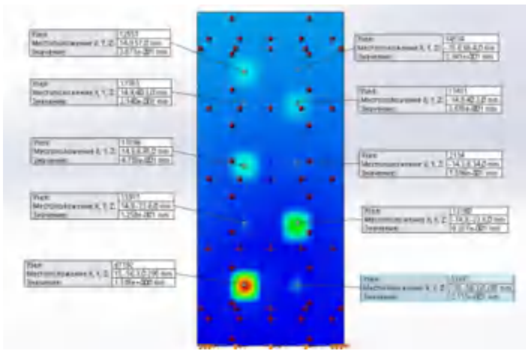

Fig. 3. Determining the value of displacement for the points of the tested object surface

When using testing methods based on high-resolution interferometry (shearography, speckle-interferometry, holographic interferometry), the presence of a defect can be determined only when the displacements of the surface points are not less than the sensitivity of the device or the experimental setting by which testing is carried out. Thus, using this model, it allows to determine the minimum level of load required to show all defects, the size of which exceeds the permissible according to the technical requirements.

At the same time, the possibility of using certain load value is determined. As a rule, the requirements for the technique of non-destructive testing assume that the load of the object during the control should not exceed 5% -10% of the fracture load. That is, by simulating the deformation process of the tested object at different load levels, one can determine its required value to ensure the reliability of the testing data and the integrity of the tested object.

The calculated interferogram of the object under thermal load (Fig. 4) has only five anomalous zones, the location of which corresponds to the layout of the defects in the model design, with two of them, corresponding to defects number 2 and number 3, located more than three layers from surfaces, appear very vague. The analysis of the figure leads to the conclusion that the thermal load for testing of such a design is not effective enough, since only defects of large size are detected. In this case, even large defects located at a sufficient distance from the surface almost do not affect the configuration of interference fringes. That leads, with insufficient qualifications of the control operator, to the possible defect passage.

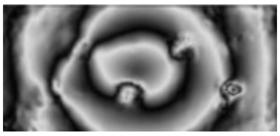

Fig. 4. Interferogram of the tested object surface during heating in the presence of defects of "non-adhesive"type between layers

The results of simulation of the structure load with the help of vibrations (Figure 5) lead to the conclusion that the detection of defects of the "non-adhesive" type is possible only for forms of higher order oscillations. This is confirmed by the calculated interferograms (Fig. 6).

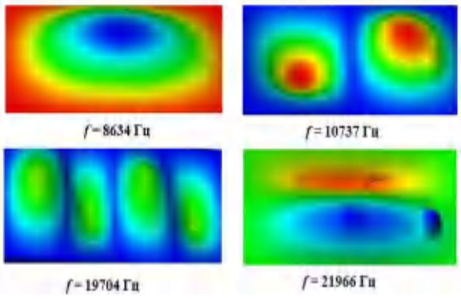

Fig. 5. Estimation models of various forms of oscillations of the multilayered structure with defects

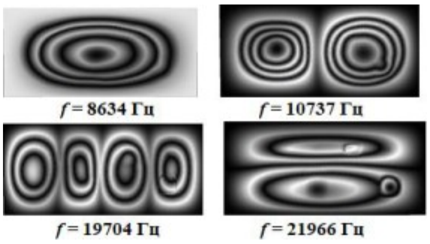

Fig. 6. Estimated interference portraits for various forms of oscillations of the multilayered structure with defects

Analysis of calculation models shows that, as with a thermal load, only defects of a large size located near the surface are detected. It can be assumed that an increase in the intensity of the oscillations and their frequency will lead to more effective detection of defects, but with this there are problems ensuring the integrity of the tested object and stability of the elements of the interferometer.

In the simulation of deformations of the structure under vacuuming loading, as an input parameter, the modulus of elasticity of the Getinax was used in the range from 9,8 to $17{,}1 \cdot 10^3$ MPa, the vacuum load value equal to $3 \cdot 10^3$ MPa.

The result of the simulation is presented in Fig. 7.

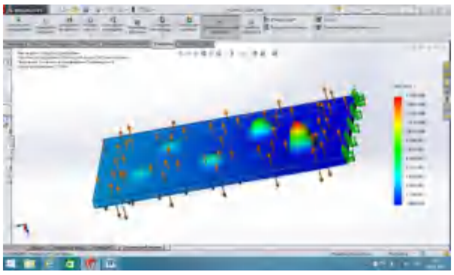

Fig. 7. Calculated model of surface displacement of tested object under the influence of vacuum load in the presence of defects of "non-adhesive" type between layers

With non-destructive testing of multilayer structures, it is essential not only to determine the presence, location and size of defects, but also to determine the defects location depth. A series of computational experiments was conducted to investigate how the defect location depth affects the deformation of the surface. Having made such a simulation, one can determine the dependence of the displacement value on the location depth and the defect area at a given load level (Fig. 8, 9).

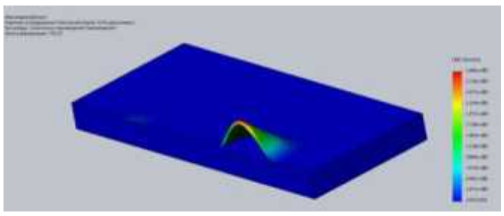

Fig. 8 Model of deformation at a vacuum load in the presence of defects under the second layer of Getinax

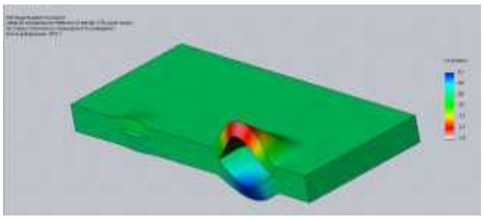

Fig. 9. Model of deformation at a vacuum load in the presence of defects under the fourth layer of Getinax

In fig. 10 is the result of calculating the interference image for the model under study at a vacuum load, which clearly revealed all the defects.

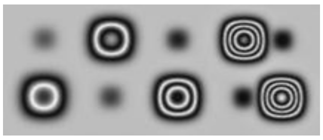

Fig. 10. Computer model of the holographic interference image of multilayered construction in the presence of "non-adhesive" defects

The simulation results not only confirmed the possibility of testing this construction by the method of holographic interferometry, but also demonstrated a clear dependence of the density of interference fringes on the depth of the defect location. Thus, we can conclude that the vacuum load is optimal for testing the multilayer construction by interferometric methods.

Computer simulation of tested object surface images, obtained by applying different loads, allows you to create a digital atlas of design defects. Defects atlas can be used to create intelligent non-destructive testing systems at the stage of machine learning. An example of such a system is the visual quality control system developed by IBM, which is based on the image recognition of tested objects using big data analysis technology Watson Analytics [5].

The results of computer simulation of interference images are also proposed to be used for control samples quality control for acoustic testing. In the presence of deviations of the interference image of a control sample obtained during an experimental test, from an image created by computer simulation, it can be argued that the physical-mechanical characteristics of the control sample differ from the technical requirements, resulting in a decrease in the reliability of testing.

Summary

The results of computer simulation of the object deformation process allow to carry out a preliminary examination of the possibility of using the selected methods and devices of non-destructive testing for products considering their physical and mechanical properties.

In the process of modeling, the optimal level of load is detected and the dependencies between the informative parameters of testing and the characteristics and conditions of the load applied to the tested object are established. This allows you to increase the informativity and reliability of testing.

Preliminary modeling of testing results considering physical and mechanical properties of a tested object allows to establish the conformity of a real object to the technical requirements, registered in the documentation. This allows to improve the quality of manufacturing of control samples used for acoustic testing.

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