About possibility of detecting micron-size defects in layered structures using the method of microfocus tomography

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Abstract. The paper describes the experience of detecting defects in layered structures using microfocus tomography. The basic features of the equipment for microfocus tomography are given. The sizes of defects (pores and inclusions) and their location in the object are analyzed.

1. Introduction
Quality control is an important part of the manufacturing process in any industrial sphere, because quality is the most significant criterion of product reliability, and therefore its safety and trouble-free operation. Currently, when controlling finished products, it is customary to use several types of non-destructive testing:

- visual-measuring control;
- acoustic (usually ultrasonic) control;
- capillary methods of nondestructive inspection;
- magnetic methods;
- X-ray inspection.

At the same time, taking into account the latest trends in the development of technologies and equipment for non-destructive testing, a special place among the main methods take ones, based on the use of precisely X-ray units [1, 2]. This fact is due to the possibility of determining the defects with the smallest, in comparison with other methods, dimensions. Perhaps, the top disadvantage is the summative form of the output data obtained (X-ray images). Eliminate this drawback – the use of X-ray tomography.

When using tomography, the study of the internal structure and detection of defects in the volume of the controlled article is carried out by visual analysis of images of individual flat sections (tomograms) of the restored spatial structure. Thus, it is possible to control in detail the geometric structure and the character of the volume distribution of density and elemental composition without destroying the product.

2. The object of study
In recent years, substantial interest research and development in the field of additive manufacturing and composite materials. Among the latter are separately allocated polymeric composite materials
used in the aircraft engine building. Their manufacture and study of properties is given considerable attention. In this case, special requirements are imposed on the means of control and diagnostics [3].

In general, a product made from polymeric composite materials is a layered structure with alternating carbonaceous fibers (in some cases glass fiber is also used) and a binder that are pressed together. Obviously, such a technology making possible the presence of defects between the layers (pores, inclusions, folds, etc.). As the object for the research was the blade of aircraft engine, having a fairly complex form (figure 1). The specified product is in the process of operation under high loads and presence of defects depends on both its reliability and service life.

![Figure 1. The object under investigation – blade made of composite materials.](image1)

3. Equipment and methods of conducting research

The work was carried out in the laboratory of X-ray systems at the department of electronics and devices in Saint Petersburg Electrotechnical University "LETI". The study was performed on the prototype of microfocus X-ray computer tomograph (figure 2).

![Figure 2. Microfocus X-ray computer tomograph: (a) – appearance; (b) – the source and receiver of radiation with the movement system.](image2)

As the radiation source used is specially designed microfocus X-ray apparatus based on sealed type X-ray tube with grid control and external anode [4]. This allows to achieve the minimum focal
length is 1 mm and the dimensions of the focal spot at the level of a few micrometers. For the registration of the projection data uses a digital flat panel detector based on the matrix of thin-film transistors with a phosphor of cesium iodide. The use of this equipment allows to obtain projection data with magnification up to 200 times and, given the size of the pixel X-ray detector, to achieve a resolution of 2–3 μm.

4. Experiment
The study sample was mounted on a special movable object table. In the process of research table rotated by a specified angle. Taking into account the chemical composition, size, geometry and spectral sensitivity of the X-ray detector, the values of anode voltage and anode current were 90 kV and 35 μA, respectively. The number of projection data was 800. Projected increase was based on assumptions about the size of possible defects of the internal structure and made up 7 times. This has resulted in a voxel size of the reconstructed image at the level of 15–16 μm.

Based on the obtained projection data were produced layer-by-layer reconstruction of the internal structure of investigated object by the method of inverse projection with filtering by convolution. After the specified operation, for ease of presentation the results of the study were performed three-dimensional reconstruction (figure 3).

Figure 3. Three-dimensional models: (a), (b) – appearance; (c), (d) – the presence of defects such as pores.

5. Conclusions
During the analysis of the data revealed the following defects:
– the pores in the surface and deep layers;
– the inclusion of foreign materials.

The dimensions of these pores and inclusions range from 30 µm to 0.15 mm. The distribution of defects within the object is uneven. Pores of small size are arranged in sections according to their geometry is close to flat. Large defects are located at corners and kinks. It is the latter pose the greatest danger, since they are in areas with the highest loads.

The obtained results should be used in the testing of technological modes of production details, as well as the establishment of numerical criteria for the acceptable number of pores and inclusions in products from polymer composite materials. Studies have shown the possibility of detecting small size defects in layered structures with high detail.

Acknowledgments
The work was supported by the Russian Science Foundation in the framework of the project «Creating portable systems for microfocus radiography with the purpose of operational control of the microstructure, physicochemical properties and determining the residual life of aircraft parts and assemblies made of composite materials». Number of project 15-19-00259.

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