UDC 620.179.1:620.178.7

O. Rugain, PhD, D. Tiurin
(National Aviation University, Ukraine)

Thermal methods for monitoring aircraft defects

The article deals with the problem of detecting defects in multilayer structures of modern aircraft by the method of active infrared thermography. Attention is also paid to alternative strategies for existing external sources of thermal excitation, which are called hybrid thermographic methods.

Currently, a large number of multilayer structures based on polymer composite materials (PCM) are used on aircraft (AC) for various purposes, both domestic and foreign.

PCM are materials that have the following set of characteristics:

- most of them do not occur in nature (are artificial);

- consist of two or more components differing in their chemical composition and separated by a pronounced boundary;

- have properties that differ from the properties of their constituent components;

- heterogeneous on the microscale and homogeneous on the macroscale;

- the composition, shape and distribution of PCM components determines its physical and operational properties;

- properties are determined by each of the components, the content of which in the material must be quite definite, and, as a rule, given.

Most of the structures made of PCM are elements consisting of a sheathing and a filler enclosed by it. They have high rigidity and relatively low weight, and therefore their use continues to increase. However, the stiffness indicators can be maintained only under the condition of the integrity of these structures, the absence of such defects as separation of the filler from the skin, destruction of the filler. In turn, the aviation industry continues to grow in the use of PCMs for various elements of the aircraft structure.

The use of new materials (PCM) is possible only if there are means of their non-destructive testing. In this regard, a large number of works are carried out on aviation equipment using various methods and means of non-destructive testing (NDT) of structures. Based on the results of diagnostics, an assessment of the technical condition is carried out. The criterion for assessing the technical condition of multilayer elements is the total area of defects.

One of the NDT is a method of non-destructive thermal testing (NDTT), which has long been known and widely used in many industries. NDTT uses energy that is forcibly distributed in the object under study. The thermal field (TF) arising in it serves as a source of information about the state of the object and about hidden defects. The introduction of NDTT into the technology of diagnosing structures of civil aviation (CA) aircraft is caused by an increase in the weight fraction of aircraft units made of PCM, and, as a consequence, the impossibility of using classical methods of non-destructive testing. Thermal control makes it possible to identify all the main production and operational defects of units made of PCM (sheathing delamination, sheathing delamination from the honeycomb block (HB), the presence of foreign inclusions, the presence of water in the HB).

The listed types of defects are currently controlled by contact control methods (impedance, high-frequency ultrasound for the presence of water, etc.), which have low productivity and high labor intensity. NDTT allows you to increase the productivity of testing, and visualization of the results allows you to reduce the likelihood of missing a defect.

Unfortunately, NDTT is not widely used for diagnosing the state of modern domestic aviation equipment (An-70, An-38, An-74-300, An-32P, An-140, An-148 and later).

For foreign technology, NDTT began to be introduced back in the last century. Early models A310 and B767 contained only 5-6% fiberglass composites. But, already in 1986, the design of the A310-200 was modernized, which helped to improve fuel efficiency. Among the changes was the introduction of a vertical tail made of carbon fiber reinforced plastics, and wheel brakes were also made from composites based on carbon fibers.

In the A320, A340 and B777 aircraft, 10-15% of composite materials by weight were used. At this stage, the minimum amount of material was used on the load-bearing parts; mainly composite material was used for finishing work in the salons, in fairings, iron and on the plumage. In the modern A380 and Boeing787 aircraft of these two corporations, the proportion of composite materials by weight exceeds 55%. In the A350 structure, 52% of the aircraft mass is made up of composite materials, 20% - aluminum, 14% - titanium, 7% - steel, 7% - other materials. In the B787 aircraft, the ratio is similar: 50% - composite materials, 20% - aluminum, 15% - titanium, 10% - steel, 5% - other materials.

Thanks to the successful implementation of PCM in the design of aeronautical engineering and the use of NDTT, foreign aircraft manufacturers and operators have gained rich experience in research, development and application of these methods in practice.

At present, taking into account modern developments of thermal imaging control tools and the accumulated experience in its application, attention is drawn to one of the NDTT methods, called active infrared thermography (AITG). AITG is a fast and accurate non-destructive assessment method. This method is of particular importance for checking the main and auxiliary structures of aircraft and helicopters, aircraft engine parts, spacecraft components and their subsystems.

Traditional optically stimulated thermography uses external optical radiation such as flashes, heaters, and laser systems. But there are other so-called new hybrid thermographic methods. These include the following:

• ultrasonic stimulated thermography, which uses ultrasonic waves and the effect of local resonance of damage to increase reliability and sensitivity to microcracks;

• eddy current stimulated thermography, which uses economical eddy current excitation to generate induction heating;

• microwave thermography, which uses electromagnetic radiation in the microwave frequency bands to quickly detect cracks and delamination.

The main idea of Lockin's thermography is that temperature modulation, induced from outside on the surface of the controlled component, propagates as a "heat wave".

Since the wave describing the space-time dependence of temperature modulation undergoes reflections at the boundaries, like all other waves, the temperature modulation at the surface is modified by heat waves returning from the inside of the component.

A sensitive indicator of such manifestations is the phase angle between energy release and local thermal response. If the temperature field is monitored during modulated illumination with a thermographic camera, Fourier analysis performed on each pixel provides the magnitude and phase of the local response.

These two values can be used to represent relevant information as a different kind of image.

Image size is influenced by inhomogenities in optical surface absorption, infrared radiation and optical illumination distribution.

If the modulation is performed in a sinusoidal manner, this estimate is particularly straightforward, since the averaging procedures reduce the roughly 1000 original thermographic images to 4 that are 90 degrees out of phase, giving a phase image according to

$$\varphi = \arctan \frac{S_3 - S_1}{S_4 - S_2},$$

where: S_1 to S_4 denote the 4 mentioned images.

The sinusoidal modulation can be achieved by a self-learning program performed by the computer that controls the thermography camera together with the lamp power. The range of subsurface detection using thermal waves depends on the frequency of modulation; it increases with the inverse of square root. Signal phase has the advantage that range is by a factor of almost 2 higher than with magnitude [1].

Leading foreign aircraft manufacturers (such as Boeing and Airbus) use thermal control as the main NDTT method for diagnosing the state of aircraft units, made of both metals and PCM. On the NDT equipment market, ready-made hardware and software systems are offered that can solve the problems of monitoring the presence of water in honeycomb structures, delamination and non-glued areas, cracks and internal corrosion.

The experience of using thermal control to control various AC units made of PCM and aluminum alloys showed results that were confirmed by standard NDT methods. The positive experience gained shows the need to introduce thermal control into the list of NDT methods used in control in aviation. The use of new materials in aircraft construction also leads to this, where thermal control is no longer an additional, but the main method of control.

The results of the research work carried out showed the need to solve the following tasks:

- the need to introduce "thermal certification" of newly manufactured aggregates from composite materials, which will simplify the problem of identifying defects and reduce the likelihood of rejects;

- the need to develop requirements for thermal control means for solving various control problems of aviation equipment.

The study of modern approaches to control and numerical methods for analyzing the results obtained gives an understanding of the need to create specialized software and control tools that will allow implementing such complex control methods as phase-pulse thermography and thermal tomography.

At this stage of development, such developments are carried out as research projects and are not available in the public domain [2].

Implementation of the described promising technologies in the domestic aircraft industry will significantly increase detecting defects arising during aircraft operation, will facilitate and accelerate the testing process, and, consequently, the process of aircraft maintenance and repair.

References

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