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TIGHTNESS TESTING OF AVIATION SYSTEMS (Review)

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The proposed publication includes a review of contemporary methods in the field of detection of leaks of test and working media, which are intended for the functioning of systems responsible for the trouble-free operation of aircraft. A new approach to preserving the viability of modern aviation structures allows for a progressive technological cycle of leak detection and protection of aircraft from damage. Currently there are elaborated number of methods for leak detection of aircraft. Each of this approach has own peculiarities and can detect defects with different sensitivity. In this paper we compare possibilities of leak testing technologies and describe their usage for control of aviation systems. Ref. 13, Tabl. 1, Fig. 5.

Keywords: methods of leak testing, defect, nondestructive testing

Introduction. Ensuring the requirements of tightness is a necessary condition for the functioning of assemblies and systems, responsible for safety of aviation flights. These include fuel tanks and pipes, hydraulic systems, the fuselage and other elements of the aircraft [1].

All major aircraft systems are monitored for leaks during production and operation. An example is the fuel system leak testing. The design of contemporary plane tanks has large volume. As a result the place of leakage («exit» of leak) may be located at a considerable distance from the «entrance» of a leak. Therefore to determine the topology and repair the defect specialists have to remove sealant and dismantle part of the structure [2].

The process of leak testing in fuel tanks-caissons make it possible to ensure the operability of aircraft and are highly sensitive. The requirements for them are due to the flammability of the fuel components, their high penetrating ability and the need to store large reserves of fuel for flight. And ensuring of their tightness is a complex technical task [3].

The kerosene-chalk method (KCM) is traditionally used to test the tightness of aviation fuel systems. It consists in determining the locations of leaks by spots of kerosene on a chalk coating. For example, the kerosene-chalk method is defined as the stage of testing in the Directive technology for monitoring the tightness of fuel tanks-caissons of the plane AN-124 («Ruslan»). The effectiveness of the application of this method is determined by the high penetrating ability of kerosene. The kerosene-chalk method is a variant of the penetrant testing (PT) [4], but unfortunately this material is flammable. Therefore, other materials are being developed, such as colored and luminescent penetrants to replace kerosene [5].

Then ultrasonic testing is used before carrying out the KC control to detect large leaks. The acoustic method is simple and reliable in operation, do not violate technological processes and it is safe for the health of the personal [6].

A few main leak detection techniques are known [7]. A description of the leak detection thresholds of different methods is presented in the Table.

Leak detection thresholds of different methods (mbarl/s)	10	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}
Bubble test (soap painting)	----	----	----	----	----	----›							
Bubble test (air, water)	----	----	----	----›									
Bubble test (He, alcohol)	----	----	----	----	----›								
He sniffer	----	----	----	----	----	----	----	----	----›				
Halogen sniffer	----	----	----	----	----	----	----	----›					
Pressure decay	----	----	----	----›									
Acoustical	----	----	----	----	----›								
Vacuum decay	----	----	----	----	----›								
Spark tester	----	----	----	----›									
Thermal conductivity	----	----	----	----	----	----	----›						
Radioisotope	----	----	----	----	----	----	----	----	----	----	----	----›	
Halogen detector	----	----	----	----	----	----	----	----›					
Mass spectrometer	----	----	----	----	----	----	----	----	----	----	----	----	----›
Dye penetrant	----	----	----	----	----	----	----›						

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Overpressure methods can be performed by fluid or gas with which the tested element must be filled. As a fluid usually the water is used. Observing the outside surface the wetted areas show us great leaks and smaller. We observe small flows with a rate greater than 1 mbarl/s. Testing with gas, the vessel is subjected to overpressure of some bars (depending on material and wall thickness) and immerged into the water. At leaks the gas bubbles begin to escape. In this manner the leaks up to $1 \cdot 10^{-3}$ mbarl/s can be detected. If the vessel is too great for immersion, the suspected points should be painted by soap solution and again we can see the bubbles escaping, if there is a leak. This method is usable also for very large systems.

Halogen leak detectors are used in the detector-probe mode, requiring that the system be pressurized with a gas containing an organic halide, such as one of the freons. The exterior of the system is then scanned with a sniffer probe sensitive to traces of the halogen – bearing gas. The principle is based on the increased positive ions (K or Na) emission because of sudden halide composition presence. The ion current is the measure for a leak size. Halogen detectors can be used also in turned mode: evacuated vessel is connected to detecting instrument and is sprayed by freon.

Mass spectrometers as leak detectors are used as most sensitive instruments for stating leak existence and presence in vacuum systems. They are adjusted on the atom respectively molecular weight of tracer gas. It is usually helium because of its small mass and atom volume assures good supply of gas through a leak, relative great mass distance from neighbor mass enables greater sensitivity and its partial pressure in air is low. The next suitable gas for leak detection purposes would be H_2, but it is dangerous and residual atmosphere in vacuum systems always contains this gas. There are also spectrometers adjustable to other gases e.g. argon.

Ensuring the tightness of the aircraft structure is inextricably linked with the control of the integrity of critical parts. To check the performance of aviation equipment, other methods of nondestructive testing are also used. As an example of the search for surface and subsurface defects or microdefects, one can cite a technology that can lead to damage to fasteners (bolts for fastening propeller blades). Destruction of these elements can lead to a decrease in engine lift, which is equivalent to loss of tightness of the aircraft. In rapidly rotating and vibrating highly loaded engine parts, destruction, loss of structural integrity and safety can occur. Therefore, flight stability mainly depends on regular checks of critical aircraft constructions. For this purpose, magnetic luminescent particle testing (MPI) is used (Fig. 1) [8].

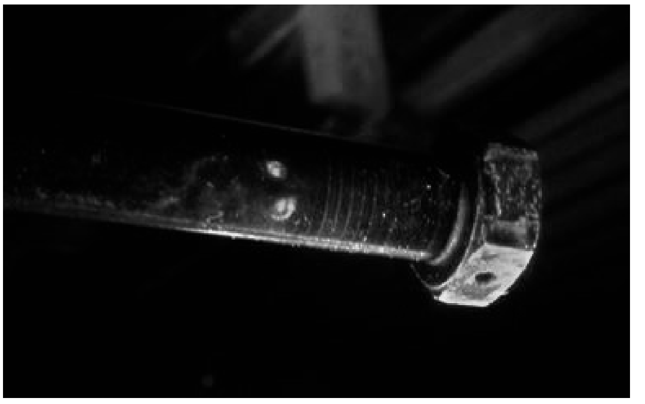

Fig. 1. Schematic indication of cracks on a propeller mounting bolt
Рис. 1. Індикація (сліди) тріщин на болті кріплення повітряного гвинта.

Review of authors' researches on methods of leak control. As an implementation option in aircraft industry of the «PT» method the so-called «bubble» method is also wide used. In the places of through defects they form the foam in the emulsion, based on surfactants. It is available for use and therefore has been long time applied for the control of tightness. Foam indicators are widely used in aviation (Fig. 2).

The sensitivity of the bubbles control is comparable to the tightness test with kerosene in the absence of a fire hazard. The use of vacuum appliance makes it possible to test the unclosed objects too. Therefore, the standard aviation fuel system test consists of a leak testing, using a foam emulsion, followed by the kerosene testing. Reserves of air are practically unlimited and available. If the defect is new or well cleaned, it contains an air only. And the operation of filling leaks by penetrants is excluded from the technology cycle. As a result the air is one of the most widely used testing substances, which is completely harmless. These benefits are the reason of traditional usage an air for implementation of «bubble» method for leak detection. This method is the oldest and most widely used for technical object's control.

Another example (Fig. 3) of the penetrant control is luminescent testing (LT) [9], in which a solution of phosphors in liquids with high penetrating ability (for example, environmentally neutral ethanol) are used. LT control differs from another leak testing methods by super high sensitivity.

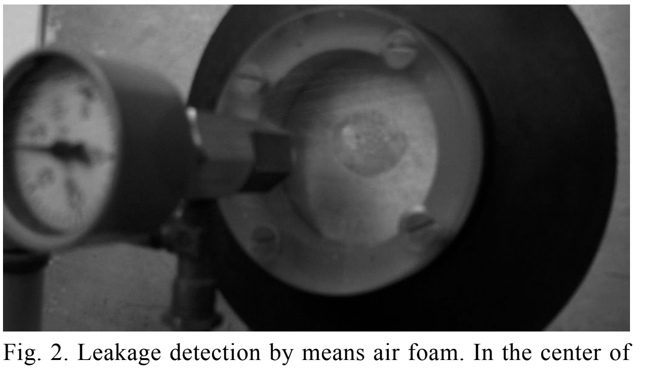

Fig. 2. Leakage detection by means air foam. In the center of vacuum appliance there is a place of defect (bubble)
Рис. 2. Виявлення витоку за допомогою повітряної піни. У центрі вакуумного приладу є місце дефекту (бульбашка)

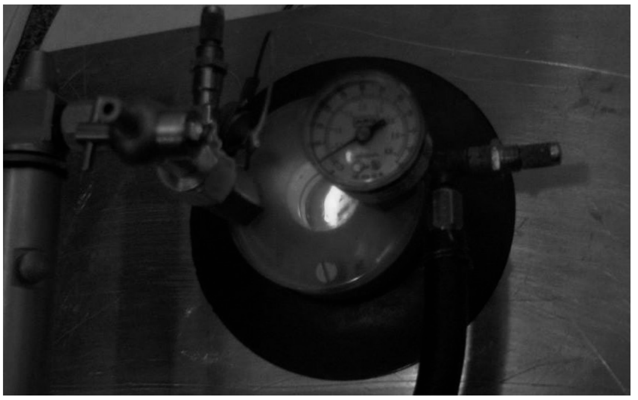

Fig. 3. Luminescent penetrant testing of aircraft constructions with vacuum appliance
Рис. 3. Люмінесцентний капілярний контроль конструкцій літальних апаратів вакуумною установкою

Unique features of luminescent capillary control (Fig. 3) allow to detect defects with the opening width less, than a micron. It is one of an evolving nondestructive methods through the use of new test materials, which improve the characteristics of penetrant control and allow diagnosing damage to aircraft skin, searching for initial centers of corrosion under paint coatings.

Today, the capabilities of penetrant testing are not exhausted. The further development of penetrant testing may be possible by new approaches. For instance, when checking the tightness of fuel tanks-caissons, it is important to determine the topology of the leak. because the inlet and outlet of the leak may not coincide due to the leakage of the working medium under the sealed internal lining of the caisson. And only fluorescent flaw detection can identify fuel leaks and simplify the technology to local repair by replacing certain fastening connections of tank parts [3].

As one of these approaches can be pointed colored penetrant «IPC-KOLOR» [10, 11], synthesized from medical raw material. It prevent corrosion, is fully un-dangerous and can be solved in water and ethanol. Many years it is produced in Ukraine.

Among the options for testing the tightness of aviation fuel systems the chemical method should too be mentioned. During its implementation the controlled volume is filled with a test medium, for example, air under excess pressure. During testing the air or liquid inside of controlled objects are enriched with chemically active additives, for example, 1 % ammonia admixture. And the outer surface is examined by using chemical indicators, that react with additives and form brightly colored or luminescent products (Fig. 4). The development of the chemical control method is the catalymetric method of leak testing. It is based on the use of micro-additives of catalytic substances in the composition of the penetrant. This approach dramatically expands the possibilities of the chemical method, since the catalyst is not consumed during the reaction. The number of elementary acts of the indicator reaction, initiated by the catalyst particle, is called the «circulation number».

Theoretically it plays the role of an amplification factor and determines the sensitivity limit of the method. The «kinetic methods» of chemical analysis are based on this principle. The use of kinetic methods makes it possible to increase the sensitivity of the analysis of substances by many times and to expand the list of penetrants. The reliability of the analysis also increases. Thus, at the locations of through defects, indicator «traces» are formed and visually determined.

Chemical control is among the most sensitive methods of nondestructive testing. It is connected with unique features of luminescent and color materials (LT, CT) and the properties of the eye, as universal tool for visual control.

These factors were contributed to the wide dissemination of the chemical luminescent and dye materials. The use of the chemical method opens up the possibility of directed synthesis and introduction of new materials including for testing such important parts as fuselage fasteners, turbine blades in engines, etc.

In contrast to the conventional luminescent method of leak control we proposed the use of chemical luminescent indicators that glow at the location of the defect as a result of the oxidation of the substrate with atmospheric oxygen without illuminating the structure. Liquid penetrants are widely used in industry for nondestructive testing. Currently, in order to increase efficiency (quantum yield) of luminescence we apply cascading composition of different phosphors. Despite the visible simplicity fluorescent flaw detection sensitivity has a record data that is not available by other NDT methods. It can detect surface defects, which have opening width, less than 1 μm.

As one of the most promising areas of the NDT penetrant method we studied the use of ultrasonic capillary effect (USCE) [9].

Fig. 4. Indication traces of leaks after chemical testing
Рис. 4. Сліди індикації витоків після хімічних досліджень

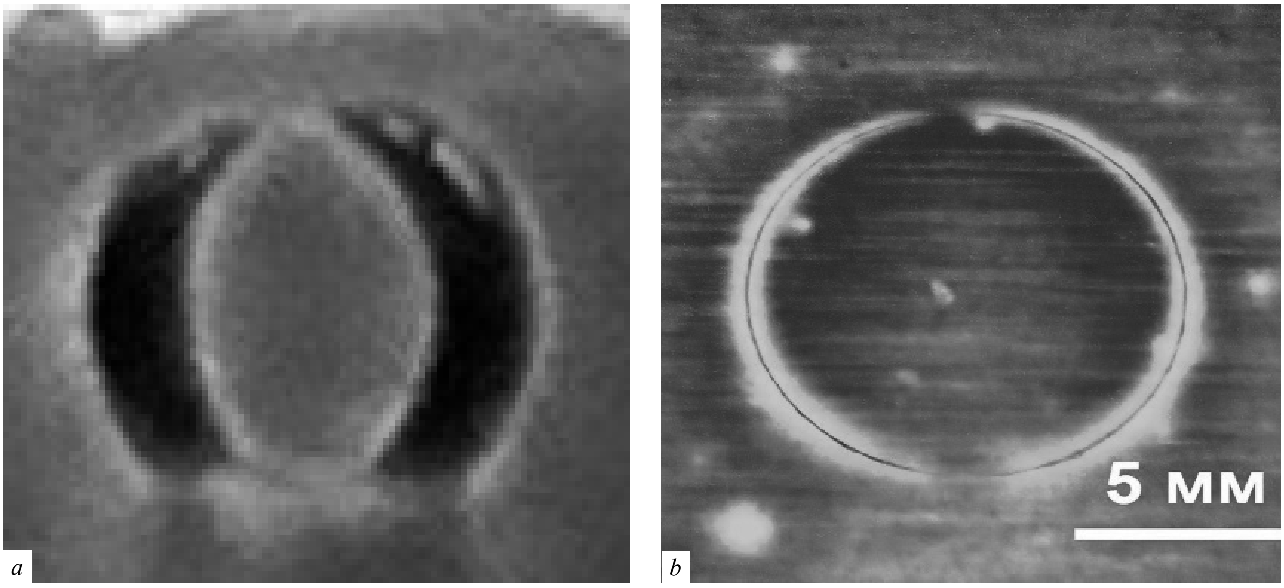

Fig. 5. Visualization of the defect: *a* – using a magnetic liquid; *b* –using a magnetic luminescent composition
Рис. 5. Візуалізація дефекту: *a* – за допомогою магнітної рідини, *b* – за допомогою магнітолюмінесцентної композиції.

USCE consists in an abnormal increase in the lifting height of the liquid in capillaries by the direct effects of ultrasound. Due to the energy of the ultrasound field (22 kHz), we received the rising of substances (colored penetrant «IPC-KOLOR» for instance) in capillaries by 10...20 times of magnitude according to capillary diameter. The dependence of USCE on the nature of the penetrant and other conditions of the experiment was investigated.

It was experimentally proved, that in this case the liquid is pushed up not only by capillary forces, but by standing ultrasonic waves. The main initiator of the physical and chemical processes occurring in the liquid under the influence of ultrasound is the formation of pulsing bubbles in the liquid, which after dramatically slam form the front of high pressure field. Due to the energy of the ultrasound field efficiency of penetration of liquid substances into the capillaries increases. This gives additional prospects for the development of capillary control.

Another promising integrated method for improving the tightness control is the way of using magnetic fluid in magnetic diagnostics of aircraft structures. It is shown that the use of magnetic-luminescent liquids in the magnetic method of nondestructive testing is characterized by high sensitivity. Magnetic fluids are sedimentation-stable colloidal solutions of magnetic particles with nano dimensions, the distinguishing feature of which is that the entire volume of the solution is drawn into the applied magnetic field [12, 13]. The combination of fluidity and a high value of magnetization allows the use of magnetization in various fields of modern technology. Due to the use of $CoFe_2O_4$ nanoparticles with sizes from 5 to 30 nm, the complex method makes it possible to detect smaller defects and reveal the fine structure of indicator «traces» in products made of ferromagnetic materials. Varying the magnetization conditions and control technology makes it possible to obtain different configurations of the fine structure of the indicator «trace» of the same defect, which contains information about the behavior of the penetrant in the presence of a magnetic field.

The combined use of capillary and magnet luminescent methods makes it possible to control defects in nonmagnetic materials with using of the magnetic fluids and increases the sensitivity of the simple capillary method. It is known that the magnetic particle inspection method is used for nondestructive testing in aviation only for ferromagnetic parts. And the applicator of the proposed method expands the possibilities of testing nonmagnetic structures with high sensitivity. Invention of these technologies in aviation is developed.

Conclusions. The article contains an overview of existing methods in the field of detecting leaks of test and working environments, intended for the functioning of systems, responsible for the safe of aircraft. Traditional and new approaches to maintaining the operability of modern aircraft structures allow the implementation of technological cycles of detecting leaks and defects of individual responsible parts and systems. Currently, technologies for increasing the efficiency and sensitivity of leak detection methods are developed. The work confirms not only the possibility of using new and different test and working environments, but also complex leak detection methods. Algorithms for improving capillary, chemical, and magnetic powder control are proposed, which increase the effectiveness of these methods and allow identification of flow topology, detection of submicron-sized defects, expansion of the list of control objects, for example, diagnosis of damage to aircraft skin, search for initial corrosion under paint coatings, etc. The issue of testing aircraft for tightness is relevant for use in aviation technology and requires further development of nondestructive testing technologies.

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КОНТРОЛЬ ГЕРМЕТИЧНОСТІ АВІАЦІЙНИХ СИСТЕМ (Огляд)

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Пропонована публікація містить огляд сучасних методів у галузі виявлення витоків тестових і робочих середовищ, які призначені для функціонування систем, що відповідають за безаварійну роботу літальних апаратів. Новий підхід до збереження працездатності сучасних авіаційних конструкцій дозволяє реалізувати прогресивний технологічний цикл виявлення течі та захисту літальних апаратів від пошкоджень. У даний час розроблено ряд методів виявлення течі літаків. Кожен із цих підходів має свої особливості та може виявляти дефекти з різною чутливістю. У цій статті ми порівнюємо можливості технологій тестування на герметичність та описуємо їх використання для управління авіаційними системами. Бібліогр. 13, табл. 1, рис. 5.

Ключові слова: методи контролю на герметичність, дефект, неруйнівний контроль

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