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NON-DESTRUCTIVE INSPECTION OF COMPOSITE STRUCTURES

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NON-DESTRUCTIVE INSPECTION OF COMPOSITE STRUCTURES

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Розглянуто основні методи неруйнівного контролю композитних конструкцій. Проаналізовано фізичні принципи реалізації цих методів, їх переваги та недоліки. Наведено рекомендації щодо їх практичного використання. Розглянуто сучасне обладнання, що використовується для оцінювання якості композитних конструкцій на етапах їх виробництва та експлуатації. Подано матеріали, які можуть бути використані студентами для курсового та дипломного проєктування, а також для обґрунтування будови створюваних композитних конструкцій та вибору їх компонентів на етапі проєктування.

Для студентів технічних спеціальностей, аспірантів і науковців.

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Main methods of composite structures non-destructive inspection is considered.

Physical principles of methods realization, advantages and disadvantages, recommendations for application are analyzed. Review of up-to-date equipment used for estimation quality of composite articles and units manufacturing and operation is given. Materials considered in the paper can be used by students for course and diploma projects preparation and also for further grounding of composite structures development, selection components for novel composites.

For students of technical majors, post graduate students and scientists.

Figs 72. Tables 5. Bibliogr.: 17 references

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CONTENTS

1. METHODS OF QUALITY CONTROL AND REQUIREMENTS TO THEM

To ensure high quality and reliability of articles made of polymer composites engineers have to use effective up-to-date methods of control at all stages of production cycle from manufacturing to operation.

Quality control can be **destructive**, **non-destructive (NDT)**, **analytical** and **metrological** (checking).

Advantage of destructive method of control is in determination of quantitative characteristics of material parameter by means of direct measuring. For example, such important parameter as strength can be determined reliably by means of destruction at necessary loading conditions. Moreover, destructive methods allow to determine article or unit lifetime at given conditions, reliability of exact part close to operational one.

Destructive methods include testing at tension, compression, heat resistance, determination of hardness, testing at thermal and electrical loads, metallographic methods etc.

Disadvantages of destructive methods are: article failure or significant worsening of its parameters, don’t ensure continuity of measuring during articles manufacturing and operation, don’t guarantee operational reliability of articles at extreme conditions, because destructive control is selective one. Many destructive methods are very labor-intensive and require attention of high-qualified personnel.

Metrological control is generally used for verification of another methods of control and oriented on determination of measuring devices and approaches precision and sensitivity.

Analytical methods belong to non-destructive methods and require application of complicated analytical models, numerical methods, and software for their realization. Precision of analytical methods depend on correctness of composed mathematical model describing real structure at operation and manufacturing.

Non-destructive methods of quality control are used both on the stage of composite articles manufacturing and on the operation stage. Process of control is conducted without operational regimes disturbing. It is possible to apply multiple checking of the same article in any time and automize this process, adjust it with manufacturing process varying technological parameters, if necessary, prevent article unpredictable failure, find internal defects and imperfections, read their spatial coordinates and estimate their dimensions. Moreover, application of NDT allows to perfect manufacturing technology by removing errors in technological equipment or imperfections of technological process steps. NDT methods possess high precision, reliability of obtained results, high sensitivity and resolution.

NDT methods are used continuously in low- and medium-scale production for estimation quality of articles. In large volume production statistical methods of selective control are more effective. In this case quality control methods are divided by **quantitative**, **qualitative** or **alternative** features.

Quantitative methods allow to register precise numerical values of parameters defining articles quality.

Qualitative methods allow to catch only categories, classes (grades etc) to which produced article belongs.

When articles must be classified on valid or defected only **alternative methods** of control are used. These methods are partial case of q**ualitative methods of control.**

But non-destructive methods are indirect by their essence, i.e. it is impossible to determine such parameters as strength, survivability etc. To determining these parameters, one has to calibrate non-destructive methods with destructive and analytical by means of special standard control gages. It is impossible to establish influence of different defects on reliability and lifetime of articles, therefore NDT methods can't answer question about how critical, significant or low-significant a defect is. Some NDT methods require exact contact with article under analysis that makes automation of measuring to be quite difficult, some of results measured require special decoding, equipment used for testing, for example, acoustic-emission method, is quite expensive. Comparative analysis of destructive and non-destructive methods leads to conclusion that no universal methods of testing and selection of the most suitable method depends on exact articles.

2. SELECTION OF THE MOST EFFECTIVE METHODS AND MEANS OF QUALITY CONTROL

Selection of exact method of quality control and forecasting reliability depends on following factors:

1) physical condition of medium under analysis (dielectric, semi-conductor, conductor, magnetic or non-magnetic material);

2) type of structure under analysis (amorphous, mono-crystalline, polycrystalline, anisotropic);

3) possibility to interact with radiation passed through material (low or high absorption, dissipation, refraction, reflection etc);

4) parameters of atmosphere in which studying is conducted (in vacuum, in liquid, at high temperature, at high pressure etc);

5) dimensions, configuration and structural distinctions of an object under analysis;

6) type of problem formulated (defectoscopy, thickness measuring, analysis of structure, control of density and viscosity, control of solidification kinetics, stress-strain state analysis, components contents analysis etc).

3. DISTINCTIONS OF COMPOSITE ARTICLES QUALITY CONTROL

NDT methods can be classified by physical phenomena realized at measuring. According to Ukrainian standard following types of methods can be applied for analysis:

- optical;
- capillary (with penetrative substance);
- magnetic;
- eddy-current;
- acoustic (ultrasonic);
- heating;
- irradiative;
- radio-wavy;
- electrical.

Polymeric composites are quite complicated objects for quality control analysis because they are generally inhomogeneous, contain multiple structures (unidirectional, cross-ply, combined etc), possess special physical properties like high electric-, heat-, sound insulative properties, are characterized by high scattering of physical and mechanical properties.

Majority of polymeric composites depending on reinforcing material used belong to dielectrics. Practically all of them are non-magnetic. Therefore, magnetic and eddy-current methods can't be used for polymeric composites defectoscopy. High-frequency ultrasonic methods with frequency more than 1 MHz can't be also used because signal is absorbed by composite, or they can be used for composites with restricted thickness. Radiation methods can be used for controlling composites density or thickness but not for finding internal defects.

Main criteria for selection methods for control are:

1) sensitivity of the method;
2) precision and repeatability of control results;
3) possibility of mechanization and automation of control;
4) realization of high productivity of control;
5) relative simplicity of control approach;
6) information ability and universality of control;
7) presence and possibility of application of standard equipment;
8) relatively low cost of control;
9) involving in control process a staff with restricted qualification;
10) realization of labor safety during analysis.

Integrated approach of quality control includes following stages:

1. Optimal complex of physical parameters is defined. Strength and other physical-mechanical characteristics of polymeric composite and articles made of them are estimated based on complex selected.

2. Optimal complex of methods and means of defected structure control is developed and realized practically.

3. Integral estimation of article workability is concluded based on complex of parameters defined by NDT methods.

4. ORIGIN AND TYPES OF DEFECTS IN COMPOSITE STRUCTURES

Creation of up-to-date aerospace objects with high quality and reliability relates to application of structural materials with advanced physical-mechanical, technological and operational properties. Composites belong to such structural materials.

Composites are hetero-phase systems created by combination of chemically different components with well-defined interface between phases. Composites are characterized by properties which no one of its initial components have separately.

Composites consist of at least of two or more components known as reinforcing material and matrix (or binder). The main function of reinforcing material is to ensure required level of mechanical properties of composite; the function of matrix is to guarantee integral operation of reinforcing elements. Physical-mechanical properties of composites are defined by properties of both reinforcing elements, matrix and by strength (adhesion) between them.

Up-to-date polymeric composites (glass plastics, carbon plastics, boron plastics, organic plastics, foam plastics etc) possess high specific strength and rigidity, high sound-, heat-, electrical insulative properties and generally have non-uniform structure with anisotropy of properties.

Application of composites for different responsible articles and units require high quality and reliability of composites. But in process of composite production different imperfections and defects appear (flaws, cracks, cavities, delaminations, violation of reinforcing material orientation and quantity etc). Such defects can be found in composite structures generally. It leads to variation of physical-mechanical properties, worsening quality and reliability of articles.

Defects are such imperfections of composite material structure which reduce physical-mechanical characteristics established by normative documents.

Defects of composite material structure include:

- defects of raw components;
- defects appeared in material processing for final composite;
- defects appeared during article or unit operation.

Table 4.1 mentions main types of raw components defects which can lead to defects in ready-made article. For example, in reinforcing material can have defects of textile processing like tearing of fibers or threads, elevated humidity etc. Matrix or binder can have improper viscosity, presence of moisture, non-uniform spatial distribution of curing agents etc. Reinforcing material is impregnated by binder in bather of impregnation machines. Main requirement to operation of impregnation is to keep required concentration and viscosity of binder, optimal contents of volatiles. Supporting binder viscosity at required level is regulated by quantity of solvent or by variation of impregnation bath temperature. Deviation of viscosity level on recommended percentage leads to non-uniform impregnation of reinforcing material, which in its turn influences on significant scattering of physical-mechanical properties, high consumption of binder and appearance of binder recess on article surface and between layers of reinforcing material.

Elevated content of volatiles leads to appearing of porosities, voids, cracking and other internal defects. Low content of volatile leads to delamination with appearing places with poor adhesion between monolayers that reduces level of physical-mechanical properties of composite and article. Volatiles content is defined by binder type, thinner concentration and by drying regimes. Long-time drying, overheating, moisture can worse binder quality due to premature polymerization.

Table 4.1

Defects of raw material

Factors causing defects appearing	Defects	Methods of control
Violation of temperature regime of ambient atmosphere	Overated or derated viscosity of binder, gelatinization of binder	Ultrasonic (US), microradio waved (MRW)
Violation of ambient atmosphere humidity	Overated humidity of reinforcement	MRW, electrical (E)
Violation of binder components ratio	Overated content of initiative and volatile binder components, binder viscosity changing	MRW, E, US
Violation of binder chemical composition	Reduction of adhesive and physical-mechanical properties of binder	US, MRW
Low quality of reinforcement hydrophobic- adhesive treatment	Reduction of adhesion between reinforcement and binder	Infrared (IR)
Violation of fibers drawing regimes and appearing defects at weaving process	Defects of reinforcing fibers (superficial flaws, internal voids, diameter changing etc)	Optical (O), IR, US

Defects related to imperfections of articles manufacturing technologies influence mainly on final article quality. Each method of manufacturing has it own typical defects.

Main sources of defects appearing at articles forming (Tables 4.2, 4.3) are non-observance of original raw material preparation regimes, condition of technological equipment and also violation of technological regimes and thermal processing of articles. Preliminary preparation of original raw material means ensuring required binder viscosity, content of hardeners, plasticizers in binder, definite humidity of reinforcing material and its hydrophobic-adhesive pre-processing.

Preliminary preparation of raw materials means ensuring required viscosity of binder, percentage of hardeners and plasticizers, determination of reinforcing material humidity and its hydrophobic-adhesive treatment.

Imperfections of structures and technical state of manufacturing equipment (autoclaves, furnaces, presses, jigs etc) and also control-measuring devices (pressure gages, thermometers, time relays etc) influence significantly on quality of producing articles. Possibility of uniform heating and cooling of forming jig has to be provided at the stage of articles and units design because non-uniform heating and cooling leads to appearing of superficial bubbles, delaminations, cracks, warping, overrated porosity of material. Such behavior has to be taken into account at manufacturing of large-dimensional articles, articles with complicated shape and very thick articles. Forming jig heating is conducted by means of hot steam, electrical and inductive heaters. Forming jig cooling is done, as a rule, by water or by flow of cold air.

Designer also has to provide gas-releasing channels for fast and entire removing of gas products and steam appeared in process of article forming. Absence of such kind of channels leads to appearing of such defects as flaws, voids, elevated porosity.

Jig design at pressing must ensure high pressure enough for creation of all article local elements taking into account the degree of press-substance fluidity. In any case jig must guaranty high precision requirements of geometrical dimensions of shape and disposition.

Violation of mentioned requirements leads to improper geometrical dimensions of articles, significant inhomogeneity of structure and non-uniformity of physical-mechanical properties distribution on different zones of an article.

Violation of pressure applied at article forming leads to appearing recess porosity, reduction of both adhesion between reinforcing material and matrix and physical-mechanical properties. Therefore, selection of optimal level of forming pressure (force) applied to semi-finished article is especially important for oriented reinforcing materials (fibers, tapes, fabrics etc).

Quality of curing degree and polymerization degree of polymers depend on thermal-temporal regime at cooling and leads to non-uniform shrinkage, warping and delamination and internal stress appearing.

Shrinkage phenomena occurred in polymer materials due to chemical, thermal and mechanical processes influence significantly on articles quality because they change not article shape only but physical-mechanical properties also. Structural defects occurring due to shrinkage phenomena is stipulated by chemical processes happened in binder and have to be always taken into account in analysis of technological processes of articles forming.

To guarantee entire curing of binder, removing of volatiles and final material shrinkage engineers use auxiliary thermal processing of formed articles. Stabilization of physical-mechanical characteristics, material shrinkage and structure directly depend on regimes of thermal processing. Violation of these regimes leads to new defects appearing, reduction of physical-mechanical properties (due to partial destruction of binder and violation of adhesion between binder and reinforcing material).

Table 4.2

Defects of forming

Factors leading to defects appearing	Defects	Control methods
Inaccuracy of resin and filler dosing	Poor resign, unequal resin and filler distribution, physical and mechanical properties reduction, local resin thickening	US, MRW
Violation of heat regime of curing and thermal processing of an article	Delamination, inner and superficial flaws, porosities	IR, US, MRW
Mismatches in reinforcing material laying-up	Deviation of fibers orientation and fibers longitudinal and lateral ratio, variation of physical-mechanical properties anisotropy	Polarizing US, MRW
Defects of technological and measuring-control equipment (pressure gages etc), violation of technological regimes of processing	Adhesive faulties, delamination, porosity, elevated roughness of surface, poor enveloping of fibers with resin, wrinkles of reinforcing layers, internal residual stress, shrinkage behavior	IR, US, MRW
Undesirable inclusions in raw materials	Foreign inclusions (metal, textile, films etc)	IR, MRW
Violation of geometrical dimensions and shape of jigs and dies, mismatches in laying up of glass-fiber packages, shrinkage phenomena	Violation of geometrical dimensions and shape of an article	US, Magnetic, MRW, optical-mechanical, Interferometrical
Mistakes occurred at structure design and analysis	Structural defects of an article (mismatches of configuration, dimensions and zones of mechanical processing, incorrect selection of reinforcing material	Visual

Process of reinforcing material preparation and laying-up is accompanied with disturbing of reciprocal orientation of reinforcing material, ration of longitudinal and lateral fibers, wrinkles appearing in in monolayers. This reduces significantly physical-mechanical properties of composite and changes material structure in article. Similar defects can occur in process of article forming due to non-uniform forces distribution in composite article monolayers. Non-uniformity of forming forces leads to shifting, declining and warping of separate monolayers and fibers in composite, appearing of crack, flaws, delamination, porosity.

Table 4.3

Types of defects at different molding methods

Method	Article type	Typical defects
Method of free molding		
Contact molding: - with rolling-on; - without rolling-on; - with layers compression	Large-dimensional articles with complicated shape, shells, large sheets	Porosity, delamination, poor curing zones, variable thickness, low physical-mechanical properties, non-uniform binder distribution, wrinkles
Molding with elastic diagram	Large- and medium-dimensional articles with complicated shape, shells	Porosity, delamination, poor curing zones, variable thickness, low physical-mechanical properties, non-uniform binder distribution, wrinkles
Molding with wet and dry methods: - longitudinal winding; - longitudinal-lateral winding; - spiral-screw winding or combined winding; - geodesical winding	Large- and medium-dimensional articles like bodies of revolution: cylindrical, spherical, torus and other shells	Delamination, poor binder content at zones of fabric overlapping, porosity
Molding with spraying	Medium-dimensional articles with complicated shape	Porosity, variable thickness, non-uniform filler and binder distribution, low physical-mechanical properties
Method of closed molding		
Pressing of pre-impregnated fabrics and linens	Medium- and low-dimensional articles with simple shape	Flaws, delamination, local porosity, non-uniform binder distribution
Compression molding	Low-dimensional articles with complicated shape made of press-materials АГ-4В, ДСВ-2Р-2М, premix, prepreg	Zones of filler local orientation violation, flaws, porosity, non-uniform binder distribution
Autoclave method	Large- and medium-dimensional articles with complicated and simple shape	Delamination, porosity, wrinkles, filler orientation violation

Table 4.3 (continued)

Method	Article type	Typical defects
Pressure casting	Medium - and low-dimensional articles made of glass-fibber filled thermo- and reactoplastics	Zones of filler local orientation violation, non-uniform binder distribution, porosity, inner residual stress
Centrifugal forming	Medium-dimensional articles like bodies of revolution	Non-uniform binder distribution through thickness, porosity, zones of filler local orientation violation
Pultrusion	Sectional and long articles	Flaws, non-uniform binder impregnation, tearing of threads and fibers
Vacuum forming	Medium-dimensional articles with complicated and simple shape	Wrinkles of reinforcement, non-uniform binder distribution

Article operational conditions is the most important factor influencing on appearing of different defects in composites. Main reasons causing defects appearing are violation of operational regimes, environmental influence, moral and physical wear of an article (Table 4.4).

Table 4.4

Defects appeared during article operation

Main factors causing defects appearing	Defects	Methods of control
Violation of operational regimes	Superficial flaws, resin pitting, delamination	US, IR
Environmental conditions changing	Absorption of inner (hygroscopic) moisture, thermal destruction	MRW, E
Physical wear of an article	Material destruction, delamination, load-carrying ability reduction	US, IR, MRW

Microflaws occur in composites even at relatively low levels of outer loads. Together with other types of influence (moisture, temperature) they can reduce drastically physical-mechanical properties of composites. A flaw is a source of stress concentration that leads to reduction of load-carrying ability of an article especially at loading with cyclic stress. Since polymer (binder) and filler have different allowable deformation and linear expansion coefficient breakage of bonding between them occur, microflaws in binder, binder pitting and fiber tearing appear. Moreover, overrated moisturizing leads to hydroscopic capillary water absorption that causes auxiliary flaw growth and impossibility of their healing.

Mistakes done at the stage of design of composite articles and units especially prone to premature article or unit failure. Unfortunately, such mistakes are found at the stage of article operation.

Article lifetime increasing depends mainly on selection of proper article shape, ensuring stable thermal-moisture regimes of article zones and precise regulations of operational conditions.

Polymeric-based composites generally have inner porosity. Moreover, they contain microflaws having shape of waved broken line with branches or without them.

Flaws appearing is a result of shrinkage stress occurred at binder shrinkage in process of polymerization.

For example, chemical reaction of polyester binder curing is exothermal, i.e. it is accompanied with large amount of heat releasing, as a result temperature inside material can reach 80^{o}C.

Stress concentration occurs due to difference in linear expansion coefficients of fibers and resin at cooling, this leads to flaws appearing in binder. To prevent flaws appearing one has to keep strongly thickness of binder layer on fabric and don't allow overrating of curing reaction.

Flaws in polymeric binder can also appear due to stress concentration from very dense parallel fibers arrangement (at biaxial tension). Composite deformation perpendicular to fibers causes significant resin deformation between neighboring fibers and flaws appearing.

Checking-up problems

1. What are main advantages and disadvantages of destructive and non-destructive methods of quality control?
2. What non-destructive methods are used for quality control of composites?
3. What are main criteria used for quality control method selection?
4. What distinctive features of composite structure one has to consider at selection of quality control method?

5. VISUAL-OPTICAL METHOD OF AVIATION OBJECTS CONTROL

Visual-optical method of non-destructive control is based on visual observation of objects by naked eye or by means of optical devices (magnifier, microscope, endoscope, boroscope etc). This method is used for revealing of different superficial defects, structural changes and deformations of articles and units of aviation objects, deviation from given geometrical shape, observation of closed structures, poor access places of airplanes and helicopters. Observation is conducted in visible light. Optical means of control are used at different stages of repair and operation of aviation objects.

Main types of defects can be revealed are:

– superficial cracks;

– corrosion and erosion damages;

– delamination;

– open cavities;

– zones of material structure changing, what lead to changing of optical properties of surface;

– places of leakage of oil and fuel pipes, reservoirs, blind plugs, thread line joints.

Main advantages of this method are simplicity of control, not complicated equipment, low labor intensity. Therefore, it is wide-spread at control of aviation objects and used during pre-planned analysis, maintenance before and after flights, out-of-schedule control in case of accidents. Generally, one can control elements of wing at loaded zones, fittings of ailerons, flaps, landing gear units, power plants mounts etc.

But visual-optical method has low confidence and sensitivity.

By method of defect registration one can distinguish three groups of optical devices: **detector**, **visual**, **combined**.

Human eye is main receiver at application of visual devices (magnifier, microscope, endoscope, devices for angular and linear dimensions measuring etc). In detector devices photo-emulsion, luminescent substances, electronic devices serve as receivers. Combined devices are used for visual observation and observation by means of detector.

At visual-optical control one can use magnifiers, magnifiers with light (micro-lamp is disposed at zone of magnifier focus), telescopic magnifiers (for distantly located articles). To observe inner cavity of objects at restricted direct access engineers use flexible endoscopes, rigid endoscopes (boroscopes) and videoscopes. Such devices have different diameter and length of operational part and possibility to record pictures of video images of surface under control.

Technical endoscopy – is up-to-date technique of non-destructive testing of materials and equipment by means of visual analysis of surfaces and units of technical objects in cases when access to them is restricted by usual means of measurement. Depending on degree of access different kinds of endoscopes can be used. Endoscopes are used for control of landing gear struts, load-carrying elements of a wing, fuel tanks, gears of reduction units of pneumatic systems.

Endoscopes (cavascopes)

Universal fiber-optical endoscopes are used for control of poor access zones and closed cavities by means of visual observation.

Endoscopes have flexible operational module of different diameter and length with controlled (distal) end. Operational part of endoscope is flexible shell inside of which two fiber-optical tows are inserted. One of them is for images transferring, second one is for light flow passing and creation of necessary level of lightness of an object under control.

Fig. 5.1 shows endoscope ЭТГ (flexible technical endoscope) which has following engineering characteristics:

– diameter of operational part – 4...10 mm;
– length of operational part – 500...2700 mm;
– observation angle – 60º;
– distal ring rotation angle – 180º;
– range of operational temperatures – -5...+45 º C.

Fig. 5.1. Endoscope ЭТГ

Endoscope ЭТГА is flexible engineering one with autonomous power supply, has following characteristics:

– diameter of operational part – 6...8 mm;
– length of operational part – 500...1500 mm;
– observation angle – 60º;
– distal ring rotation angle – 180º;
– range of operational temperatures – -5...+45 º C.

For all endoscopes deflection angle of controlled distal ring is ±180° (Fig. 5.2).

Fig. 5.2. Possible deflection of controlled distal tip of endoscopes on ±180°

Videoendoscopes (videoscopes)

Videoendoscopes are equipped with small camera on operational tip that allows to get images of studying object. It allows to record direct evidence of testing.

Universal flexible videoscope IPLEX II SX (Fig. 5.3) is compact universal device with changeable operational probes. Changeable probes have variable diameter and length. “Smooth” probe has outer Ø6 mm and length 9.6 m, “extralong” has Ø6 mm and length 19 m. Videoscope IPLEX II SX is also equipped with changeable probes with Ø4.4 mm/length 4 m and Ø6,2 mm/length 3.5 m with inner instrumental channel. All changeable probes possess measuring functions and allow to save 4800 full-color pictures on flash card. Then defects can be analyzed by means of special software.

Fig. 5.3. Universal flexible videoscope IPLEX II SX (Olympus)

Boroscopes


Fig. 5.4. Rigid endoscopes ЭТЖ

Rigid endoscopes ЭТЖ (boroscopes) are used for visual control of cavities, deep openings etc (Fig. 5.4). Their magnification is 1.5…2.5 times.

High quality of imaging is ensured by optical system of solid lenses of information channel. Lightning of operational zone is done by outer source of light through fiber-optical light guide. Technical properties of ЭТЖ boroscopes:

– diameter of operational part – 1.7...4 mm;
– length of operational part – 200...300 mm;
– observation angle – 0º, 30º, 70º, 90º;
– distal ring rotation angle – 180º;
– range of operational temperatures – -5...+45 º C.

Set of boroscopes of series 5 is very wide and includes devices with probes wit variable diameter and length, observation directions and angles.

Checking-up problems

1. What defects can be revealed by visual-optical method?
2. What equipment are used for control by visual-optical method?
3. What are main advantages and disadvantages of visual-optical method?

6. REVEALING DEFECTS IN COMPOSITES BY CAPILLARY DEFECTOSCOPY METHOD

Capillary control is non-destructive methods of control based on capillary penetration of indicating liquids (penetrants) to cavities of superficial and through thickness discontinuities of object material under analysis.

Capillary method is very simple and allowable, recommended for revealing of through thickness and superficial discontinuities. It allows to determine length, direction and character of defect distribution in controlled article (Fig. 6.1) in articles made of metals, plastics and other solid structural materials of any dimensions and shape.

According to the ГОСТ 18442-80 capillary methods and penetrants are classified by luminescent, colored, luminescent-colored, brightness (achromatic).

Technological stages of control are the same for all methods but final stage of observation and presorting differs: at colored method controlled surface is illuminated with natural light but at luminescent – by ultraviolet light depending on used set of defectoscopic materials.

Luminescent-colored method requires lighting by visible light and ultraviolet radiation. Colored method reveals defects as red dots and lines on white background, luminescent one reveals defects as yellow-green luminescent lines and dots on black background.

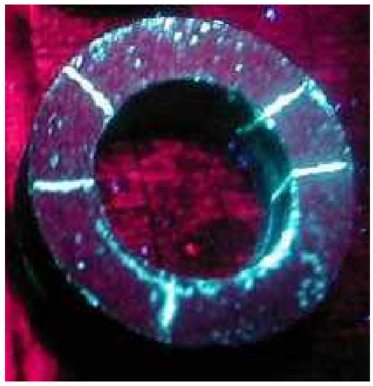
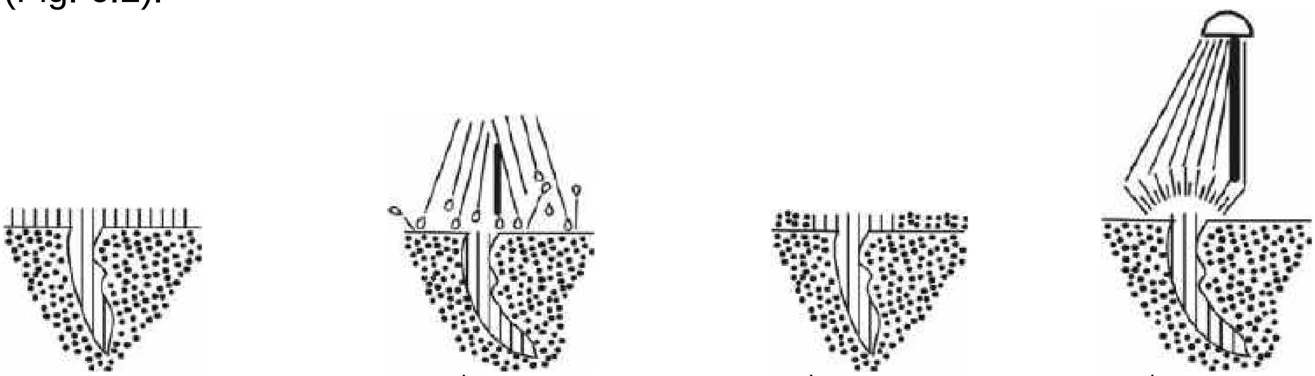


Fig. 6.1. Superficial defects revealed by luminescent method of inspection

Main principles of the method

Preparation of objects to control procedure includes cleaning on controlled surface and cavities from contaminants, protective coatings etc.

Process of capillary control can be divided by three main stages: application of liquid penetrant to controlled surface, excess of penetrant removing from surface, revealing of indications. At capillary control conduction following set of materials is used: penetrant, cleaner, revealing regent. Liquid with high surface wettability is applied to controlling surface (Fig. 6.2).



1st stage 2nd stage 3rd stage 4th stage

Fig. 6.2. Stages of capillary control conduction

Colorizing agent or luminescent agent (luminophore) is added to the liquid. Indicative penetrant penetrates to open superficial defects, after that excess of the agent is removed from controlling surface by means of different cleaners.

Then article surface is covered by revealing agent. As revealing agent one can use white paint or powder with high adsorbing ability. Adsorbing substance draws excess of a liquid from defect and changes to color of colorizing agent at the place of defect location or is wetted by liquid with luminescent agent which become fluorescent at radiation with ultraviolet beams. Got indicative picture is more visual than real defect. Revealed indications must be analyzed clearly and controlling articles have to be fully cleaned from the rest of defectoscopic materials.

Defectoscopic materials and methods of their application

There are several of defectoscopic materials application depending on article configuration (degree of surface geometry complexity): by article immersing

Fig. 6.3. Aerosol container for penetrant application

to a bath or by aerosol spraying.

Mostly aerosol containers are used for penetrant application (Fig. 6.3). Aerosol containers allow to escape of brush usage, no excess of materials, they are useful for storage and application. Penetrant can be applied to separate zone only where one needs to conduct controlling (Fig. 6.4).

a b c

Fig. 6.4. Stages of penetrant application

Special fluorescent substances can be added to penetrant because they give vivid lighting at their radiation with ultraviolet light. In this case inications are revealed as lighting, generally, with yellow-green color traces. Besides, many manufacturers produce penetrants containing properties both colored and fluorescent materials, so-called fluorescent-colored penetrants. In this case analysis of testing results can be done at both usual and ultraviolet lighting. However, controlling in ultraviolet lighting in more effective and reveals more quantity of defects comparing with analysis at usual light.

Penetrant can be removed by dry or wetted by water or special cleaner napkin. Revealing agent is always applied after surface drying at application of aerosols. Revealing agent must be applied by thin uniform layer. Revealing agent must be slightly wet to draw penetrant to surface from cavities of defects. Revealing agent layer thickness has to be enough to guarantee adsorption of colorizing penetrant and contract wight background to reveal defects with red colorizing penetrant.

But layer must not be very thick otherwise it will hide or darken red indicator traces of defects. Therefore, it is better to ally two or three thin layers of revealing agents than one thick.

Indication traces of defects begin to reveal only revealing agent dries but final control can be conducted in 15…20 minutes after total defects revealing.

Rate of revealing, color depth and picture of indication trace define defect type. Red lines evidence about crack presence. Thin cracks are revealed as dots crating line, porosity is revealed as scattered red dots.

Criteria of good quality articles selection are defined by normative documents depending on article operational conditions, defect dimension, its position and type of indicating trace. Following designation of defects is used at capillary method of analysis: А – single defect; Б – multiple defects; В – continuous defects. Designation by defect direction:

|| – defects parallel to article direction;

⊥ – defects perpendicular to article direction;

Z – defects applying angle to article direction.

Revealing agent left on surface is removed by napkin wetted with water and then by dry napkin. If material is susceptible to corrosion after revealing agent removing special treatment preventing corrosion has to be conducted.

It is necessary to select defectoscopic materials of necessary type and class of sensitivity depending on requirements to object of control, article material, its state, conditions of control and requirements to resolution capability. Generally, such materials are brought up to sets, containing compatible defectoscopic materials: indication penetrant, cleaner for controlling object and revealing agent for penetrant. Compatibility of defectoscopic materials in a set is obligatory condition.

At revealing of through the thickness objects the difference of controlling procedure is the following: to one surface of controlling object penetrant is applied and revealing agent is applied to opposite surface. This technology is known as “controlling of leakage” and used for thin-walled reservoirs, pipelines and tanks. One side, for example, inner surface of reservoir is covered with penetrant. Another side is covered with revealing agent. Colorizing penetrant passes through defect and when it reaches opposite side defect is revealed as red indication trace on white background.

Application of the method is restricted (mainly at control of leakage at seeking of through thickness discontinuities) by limit of capillary effect of applied consumptive materials and by form of capillary path.

Sensitivity of capillary control method

Capillary control possesses high sensitivity to superficial defects. Sensitivity of capillary method is characterized by ability of reveal reliably (with pre-defined probability) minimal (by dimension) superficial defect by its indication trace in given conditions. Sensitivity of capillary methods depend on purity of surface treatment, quality of article surface preparation, defect character, selected method and set of defectoscopic materials, keeping parameters of control technology, temperature of article and ambient atmosphere etc.

Depending on minimal dimension of revealing defects (width of exposure) it is established four classes of sensitivity of capillary methods of non-destructive inspection: 1st class – less than 1 μm, 2nd class – 1…10 μm, 3rd class – 10…100 μm, 4th – 100…500 μm. Developer of an article selects sensitivity class.

Range of sensitivity of capillary defectoscopy is restricted by upper and lower limits of revealing defects dimensions.

Upper sensitivity limit is defined by maximum value of long defect exposure. This value restricts revealing of defect with given defectoscoping materials and by correspondent technology due to intensive removing of indicative liquid from the outfall of defect cavity.

Lower limit of sensitivity is defined by minimal value of long defect exposure. This value restricts revealing of defect with given defectoscoping materials and by correspondent technology due to reduction of colorizing ability of small amount of indicative liquid.

Levels of sensitivity of penetrant systems is defined by following:

– sensitivity level 1/2 – ultralow;
– sensitivity level 1 – low;
– sensitivity level 2 – average;
– sensitivity level 3 – high;
– sensitivity level 4 – ultrahigh.

Numeration of sensitivity levels by MIL-I-25135E, AMS-2644 and by GOST 18442-80 doesn't coincide. In American standard sensitivity level 1 means low, by GOST sensitivity level 1 is highest. Sensitivity level of defectoscopic materials is estimated by means of comparison of qualification testing results with indexes of correspondent master sample by quantity and vividity of indication traces of revealed defects on testing panels.

The cost of materials is directly related to sensitivity of a system and application of higher sensitivity than required leads to unnecessary expenses.

Universal test-specimen Z-5 (PSM-5) known as panel TAM is used at checking of entire technological system of capillary control. These test-specimens are not means of for sensitivity determination, they can't be used for sensitivity comparison of different penetrants. These tests are means for checking technology of capillary control to correspondent class of sensitivity and can be used for the single penetrant system. Test-panel PSM-5 is used for control of capillary process in total. Test-panel is made of stainless steel (thickness – 2.3 mm, dimensions - 10x15 cm). From operational side test-paned is covered with chrome plating and has five asterisks-like defects. Dimensions of defects are disposed by their increasing. At capillary controlling defects are revealed as asterisks-like indications. The biggest defect become visible after treatment with low-sensitive penetrants. The smallest defect is difficult to observe even at application of high-sensitive penetrant. Picture of defects varies from panel to panel.

Control specimen (EN ISO 3452-3) is used for determination sensitivity of penetrant systems. It consists of four test-panels, i.e. bronze plates with dimensions 100x35x2 mm covered with NiCr-layer with thickness 10, 20, 30, 50 μm.

On NiCr coating lateral cracks are done, depth of cracks corresponds to the thickness of NiCr coating. Ratio of crack width to its depth is 1:20. Test-panels with crack depth 10, 20, 30 μm are used for sensitivity control of fluorescent penetrant systems. Sensitivity of contrast penetrant systems is defined by means of panels with crack depth 30 and 50 μm.

Test-panel divided by four segments (25x3 mm) with different degree of roughness (2.5; 5.0; 10.0; 15.0 μm) and five asterisks-like samples of cracks disposed over segments to control degree of fluorescent penetrant removing.

Depending on required production volume and article mass different degree od automation of controlling workshop can be suggested: from monolithic inspection station up to automized lines of closed cycle of articles transportation.

For example: articles are moved in special transportation baskets or by means of special fittings; by monorails moved by hand drive or by motor through chain transmission; by lifting and dropping devices articles are immersed to capacity (bath) with reagents or covered with reagents by spraying system installed by perimeter of air tight chamber (Fig. 6.5).

Fig. 6.5. Mechanized line with transport system of multi-roller conveyor track and mechanisms for articles lifting and dropping to a bath with reagents

Advantages of capillary control:
– high sensitivity of defects revealing;
– wide spectrum of controlled materials;
– checking of articles with complicated geometry;
– possibility of application methods with different sensitivity;
– high confidence and repeatability of results;

– simplicity and low cost;
– high production ability at in-line inspection.

Disadvantages of capillary control:
– can reveal superficial defects only;
– can't be applied to porous materials;
– it is necessary to clean dirty surface before inspection, presence of contaminants reduce efficiency of inspection;
– it is impossible to inspect surface with protective coating;
– low temperature reduces the method sensitivity;
– defects with large width (more than 500 μm) of exposure can't be revealed by capillary methods;
– short period of surface contact with penetrant reduces defects revealing;
– some materials (rubber and plastics) are not chemically stable to penetrant;
– quality of inspection depends on operator qualification.

Checking-up problems

1. how to conduct quality control by capillary method? Compose the list of technological stages of controlling.
2. What defects can be revealed by capillary method?
3. What types of capillary methods of quality control do you know? What are main distinctive features of them?
4. What are main advantages and disadvantages of capillary method. What restrictions does the method have?
5. What factors does sensitivity of capillary method depend? What does it mean upper and lower limits of capillary method sensitivity? What classes of sensitivity are established for capillary method?
6. Defectoscopic complexes, materials and auxiliary means used for capillary method.

7. ACOUSTIC METHODS OF QUALITY CONTROL OF ARTICLES MADE OF COMPOSITES

There are different problems appear at conduction of non-destructive inspection of different articles. It leads to development and application of set of different acoustic methods of inspection. Acoustic methods are widely used in engineering and cover more than 60 % of methods used comparing with other ones.

7.1. Physical fundamentals of acoustic control methods

Information got by results of analysis of parameters of elastic oscillations distribution in controlling object is used at conduction of articles inspection quality by acoustic methods.

There are several difficulties appeared at application of acoustic methods of inspection at composite articles checking. First, it is reduction of sensitivity due to high damping od elastic oscillations. It is recommended to use excitable oscillations with frequency less than 1 MHz at ultrasonic testing of composites due to significant damping of oscillations. However, reduction of a frequency leads to simultaneous decreasing of resolution capability and sensitivity of ultrasonic inspection. Secondly, high technological scattering of density, non-uniform structure, anisotropy of acoustic characteristics, low quality of contact surface led to high level of structural interference compared with or even overexceeding level of signals from defects.

It is possible to select seven main acoustic methods of non-destructive inspection: echo-method, shadow method, resonance method, impedance method, method of free oscillations, velo-symmetrical method, acoustic-topographic method.

7.2. Ultrasonic defectoscopy

To reveal defects in article under analysis one sends ultrasonic waves (continuously or as short signals) and register parameters of waves passed through article of reflected from surfaces on which acoustic characteristics of material are changed. In ultrasonic defectoscopy waves of following types are used: longitudinal, superficial, bending, twisting, irradiated in continuous or impulse regime.

Excitement and signal reception is generally based on piezo-electrical effect at ultrasonic control.

In this case ultrasonic oscillations are excited by means of transducer which transforms electrical oscillations to acoustic ones (so-called inversed piezo-electrical effect).

Reflected signals passed on piezo-plate are converted to electrical ones so-called (direct piezo-effect) and registered by measuring circuits (Fig. 7.1).

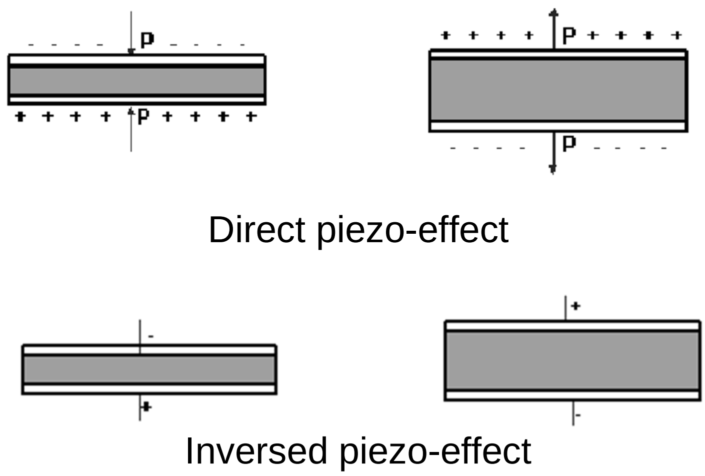


Fig. 7.1. Direct and inversed piezo-effect

Active element of piezo-electrical transducer (PET) is made of material having piezo-electric properties, its side surfaces are covered with metal and fulfill a role of electrodes. If electrical voltage is applied to electrodes piezo-element changes its thickness due to phenomenon of inversed piezoelectrical effect. If voltage is alternative then piezo-element oscillates in time with voltages sign change creating elastic oscillations in ambient medium, i.e. it works as emitter. And vice-versa if piezo-element takes mechanical oscillations electrical charge appears on electrodes due to phenomenon of direct piezo-effect.

Main characteristics of the method are sensitivity, maximum depth of inspection, minimal depth (so-called "dead" zone), resolution capability, precision of distance measuring, production volume of inspection.

Sensitivity of the method of ultrasonic defectoscopy is defined by minimal dimension of a defect disposed on maximum depth and registered clearly by measuring device. Numerically sensitivity is defined by sensitivity threshold. For echo-method it is minimal area of artificial defect like flat-bottom hole which can be found at inspection. Sensitivity threshold is restricted by two main factors – by device sensitivity and level of interference. Depending on material structure sensitivity threshold also changes.

Sensitivity *K* of the method of ultrasonic defectoscopy depends on frequency of ultrasonic oscillations *f*, article thickness in current section, acoustic characteristics of an article material under observation (dissipation factor δ and level of structural interference).

Value of K rises with frequency f increasing because at decreasing of *λ/d* (*d* – defect dimension) energy of sound wave reflected from defect surface increases and orientation of radiation and receiving increases. However, at the same time oscillations damping increases at frequency elevation due to absorption and dissipation and the level of structural interference also increases, such situation leads to sensitivity decreasing. As a result of simultaneous influence of above-mentioned factors dependence of sensitivity *K* on frequency of ultrasonic oscillations *f* have the view of a curve with maximum, i.e. the best sensitivity corresponds to definite frequency.

Maximum depth of inspection is defined from the defect of given dimension by maximum distance at which defect cab be clearly detected and restricted by the condition that signal from the defect has to be more than minimal signal registered by the measuring device and more than the level of interference. This depth is also defined by parameters of measuring device. In specification on measuring device maximum duration of defectoscope sweeping is shown as maximum depth of detection. Reaching of maximum depth of detection is restricted by the same factors which disallow sensitivity increasing.

Minimal depth of detection or so-call "dead zone" is minimal distance from transducer or from article surface up to the defect at which defect can be clearly detected not merging with detecting impulse or impulse from the surface of ultrasound input.

Resolution capability is minimal distance between two the same defects at which both of them can be detected separately.

Workability of control is defined by increment and rate of scanning (movement) of transducer. At estimation of detection duration time necessary for defect research is also considered.

Impulse detection methods are widely used in practice of ultrasonic defectoscopy. This group includes echo-method and the method of sound shadow (shadow method). Let's consider main methods used in ultrasonic defectoscopy:

1. Echo-impulse method registers echo-signals reflected from defects surfaces (Fig. 7.2).

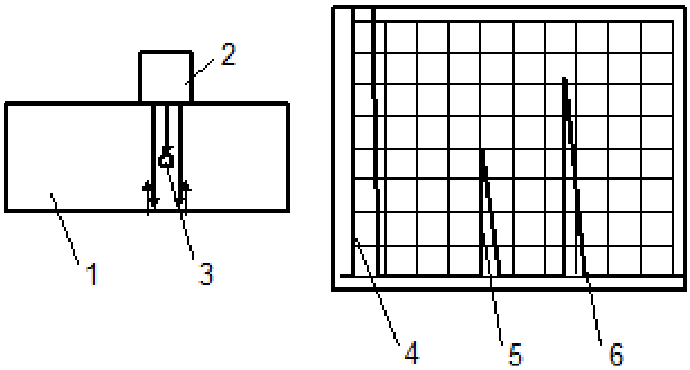


Fig. 7.2. Scheme of inspection by echo-impulse method: 1 – inspected article; 2 – PET; 3 – defect; 4 – transmitting impulse; 5 – echo-signal form defect; 6 – bottom signal

2. Mirror echo-method is based on mirror reflection of impulses from defects oriented vertically to surface from which inspection is conducted.

3. Reverberation method is developed for control of laminated structures. It is based on analysis of reverberation of ultrasonic impulses in one of layers.

4. Shadow method is based on analysis of decreased amplitude of a wave passed through defect (Fig. 7.3).

5. Temporary shadow method is based on delay of impulse caused by enveloping of defect.

6. Velo-symmetrical method is based on changing velocity of elastic waves at defect presence.

Mirror-shadow method (Fig. 7.4) is based on weakening of a signal reflected from opposite surface of an article (so-called bottom signal).

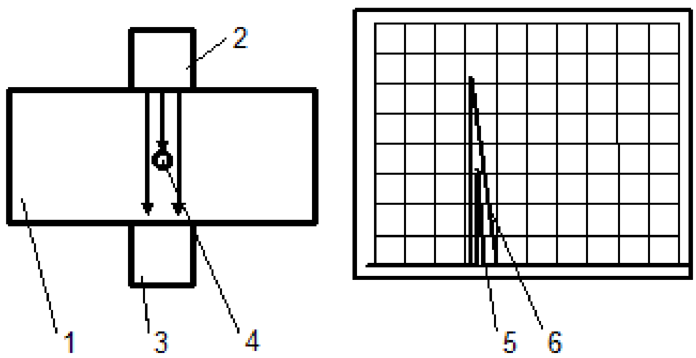


Fig. 7.3. Scheme of inspection by shadow method: 1 – article under inspection; 2 – emitting PET; 3 – receiving PET; 4 – defect; 5, 6 – bottom signals at presence and absence of defect

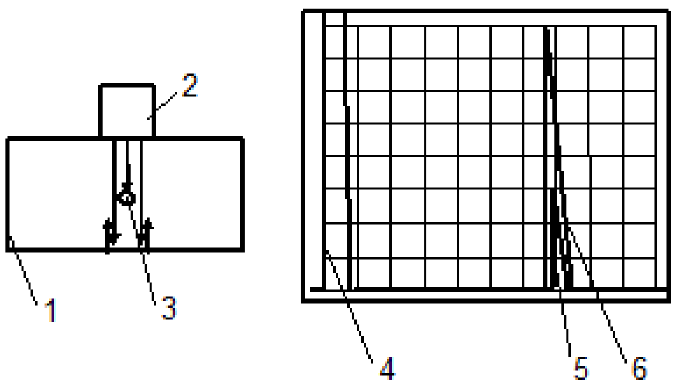


Fig. 7.4. Scheme of inspection by mirror-shadow method: 1 – article under inspection; 2 – PET; 3 – defect; 4 – detecting impulse; 5, 6 – bottom signals at presence and absence of defect

Echo-impulse method

The essence of echo-impulse method is in following: short acoustic impulses are sent to article under inspection, then intensity and time of echo-signal coming back are registered. Signal are reflected from article surface and from defects of different nature.

Emitted ultrasonic impulses are called transmitted impulses. The feature of defect presence is echo-signal reflected from discontinuity. Reflected ultrasonic impulses carry information about defect, its distance form surface or transmitter and defect dimensions. Dimensions and location of a defect is estimated by amplitude and duration of reflected echo-signal coming back.

Amplitude of a signal, reflected from defect is the simplest characteristic can be measured. It depends on dimensions, orientation, defect configuration, depth of defect location.

Depth of defect location can be determined with high precision at detection with echo-method. If type of sound wave and its velocity V of distribution inside of material under analysis, then the length of the way r passed by ultrasonic impulse from emitter to reflection object and back can be found as

$$2r = V\,t,$$

where t – duration of «delay» of received reflected impulse with respect to emitted one; r – distance from emitter to reflecting object. Total time of delay t consists of duration of ultrasonic impulse passing inside of article, duration of impulse passing through protector (or prism) of transducer and thorough layer of contact liquid, and duration of delay inside electronic block of a defectoscope. However, duration of mentioned delays is comparatively short with duration of ultrasonic impulse passing through analyzed article, therefore we can neglect by such durations.

Advantages of echo-impulse method:

- ultrasonic defectoscopy is one of the most universal methods of non-destructive inspection due to large amount of controlled parameters (amplitude, phase, frequency, velocity of waves distribution etc);
- the method allows to solve many problems: to determine dimension, orientation, configuration and depth of defects location;
- the method is very simple;
- it has high sensitivity;
- it allows to determine defects coordinates with high precision;
- it allows to conduct control at single-side access to an article;
- it ensures high labor intension and confidence of control with possibility of documentation recording, consequent analysis with software, creation of defects databases and final reports publishing.

Disadvantage of the method is presence of so-called “dead zone” disposed under PET.

The principle of echo-impulse defectoscope operation is shown on (Fig. 7.5).

Generator 2 creates electrical impulses with frequency f defined by synchronizer 1 and excites piezo-element of scanner 4. Ultrasonic waves emitted by transducer pass through surface «a» to detected object 7 and spread inside as divergent bundle of rays. Rays reflect from opposite surface «b» and return to emitter, then are transmitted to impulses of electrical voltage, pass through receiving path. After that, electrical impulses can be observed on the screen of ERT 6 as pikes. Sweeping generator 3 shows signals imaging in coordinates amplitude-time, therefore distance between original signal 9 and bottom signal 10 is proportional to article thickness. When rays reach defect 8 they reflect from it and one can see echo-signal 11 from the defect on the screen of ERT. Delay between original signal 9 and signal 11 is proportional to depth of defect location inside of article. Detection is conducted by means of scanning surface of controlled article with probe scanner.

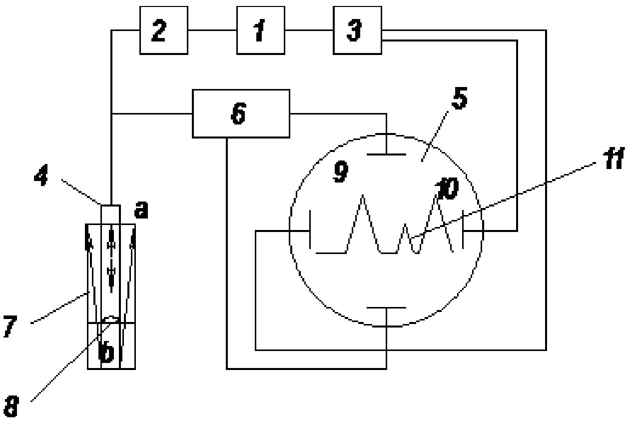
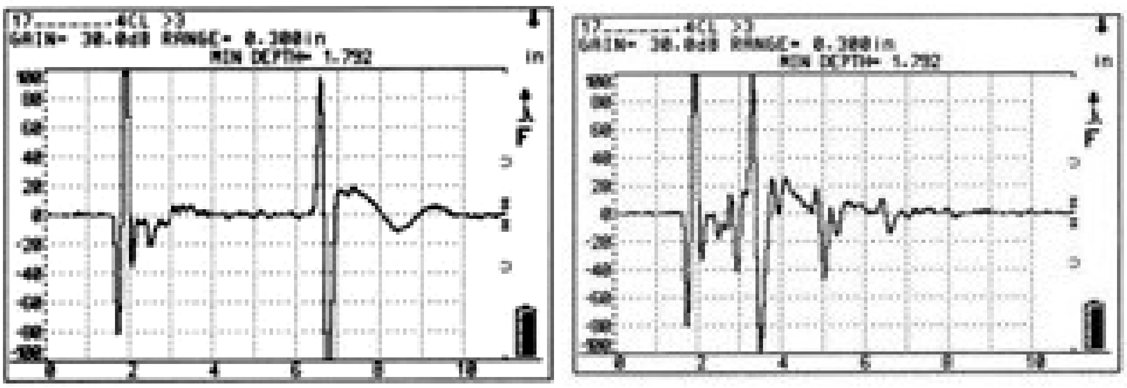


Fig. 7.5. Block-scheme of echo-defectoscope: 1 – synchronizer; 2 – generator; 3 – sweeping generator; 4 – scanner; 5 – receiving path; 6 – indicator (electronic-ray tube – ERT); 7 – article under analysis; 8 – defect; 9 – original (detecting signal); 10 – bottom echo-signal; 11 – echo-signal from defect

Fig. 7.6 shows echo-signals got at detection of composite plate used in aerospace industry.



a b

Fig. 7.6. Echo-signals got at detection of composite plate: a – echo-signals from reference specimen without defects; b – echo-signals from articles having defect

Fig. 7.6, *a* shows echo-signals from reference specimen without defects. These two signals with high amplitude represent reflection from front and rear surfaces of an article. Fig. 7.6, *b* shows echo-signals damaged by impact.

In this case interval between echo-signals is less because they represent reflection of inner delamination. Operator analyses image of echo-signals from undamaged article and then compares it with the same from images of echo-signals from damages object. Any changes of amplitude or position of echo-signals evidence about changing state of an article at the point of detection. Rate and increment of scanning are selected considering dimension of ultrasonic bundle cross-section, time necessary for impulse passing up to given surface and back and minimal quantity of echo-signals passed, which ensure registering of defects signaling indicator. Piezo-element of scanning probe in regime of irradiation converts electrical oscillations produced by generator 2 to ultrasonic ones. It converts ultrasonic signals to electrical ones in regime of receiving.

Shadow method

Shadow method is based on through thickness article scanning by impulses of ultrasonic oscillations. The method is based on measuring of reduction of elastic waves passed through detected object. Discontinuities (cracks, delamination, cavities etc) or uniformities of composites lead to changing conditions of ultrasonic waves distribution. If lateral dimension of a defect is more than wavelength λ, then wave practically fully reflects (according to laws of geometrical acoustics) that leads to creation of sound shadow zone behind a defect. In zones with non-uniform structure damping of ultrasonic waves becomes more and level of structural interference also increases. The interference is stipulated by energy dissipation on discontinuities.

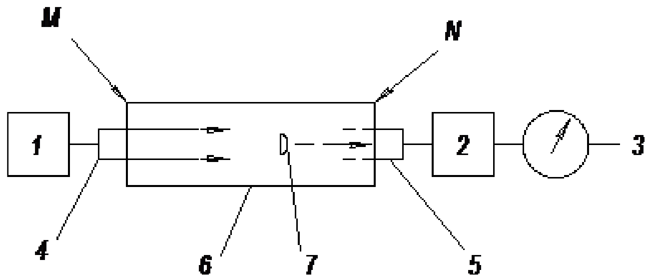


Fig. 7.7. Scheme of ultrasonic defectoscope for inspection of defects by shadow method: 1 – generator; 2 – receiving path; 3 – indicator; 4 – emitting probe; 5 – receiving probe; 6 – inspected object; 7 – defect

Two co-axial transmitters (Fig. 7.7) are used for sending and receiving of ultrasonic signal. Sending transducer of ultrasonic waves, article under inspection and receiving transducer create so-called “acoustic path” through which ultrasonic wave distributes. Conclusion about defect presence can be done by value of amplitude (level) of received signal at the exit of receiving transducer or by changing of the phase or duration of wave returning. Wave passes over defect (envelopes it), i.e. the trajectory of a wave is longer. If defects, which can reflect or dissipate wave, are absent on the wave path from the sending transducer and receiving transducer, then the level of received signal is maximum. If defect (discontinuity) is presented on the wave trajectory then one can register signal with significantly less level because ultrasonic waves pass to zone of sound shadow due to waves diffraction.

Advantages of shadow method:

– «dead zone» is absent at application of shadow method, therefore, it can be used for controlling of thin-walled articles;

– sloped defects can be also found by shadow method; sloped defects don't reflect signal directly at echo-method because it has poor dependence of signal amplitude on defect orientation;

– the method possesses high resistance to interference.

Disadvantages of shadow method:

– at application of shadow method co-axial disposition of sending and receiving transducers and stable acoustic contact with detected article have to be guaranteed;

– shadow method comes short of sensitivity and universality to echo-method;

– it is mainly used for inspection of articles having simple shape and small thickness;

– requires double-side access to inspected article;

– it is impossible to determine the depth of a defect location by the method.

Mirror-shadow method

Mirror-shadow method is combination of echo-impulse and shadow method. It doesn't differ from shadow method but is easier when single-side access to an article is allowed. This method used one or two piezo-electric transmitters disposed on the same surface of an article. The evidence of defect presence is reduction of amplitude (level) of ultrasonic wave which passed through detected article and reflected from its opposite surface. Defect dimensions can be estimated by «bottom» signal amplitude reduction.

Echo-mirror method

Echo-mirror method – is one of the most confident methods at inspection of defects which oriented vertically. The method can be realized at scanning of an article by two piezo-electric transmitters (PET), which are moved by surface in such way to record signal with one PET which was sent by another PET, and reflected two times – from defect and from opposite surface of an article (Fig. 7.8).

One of the main advantages of the method is possibility of defect shape estimation having order from 3 mm and more and twisted in vertical plane on the angle not more than 10°. One has to use PET of the same sensitivity at estimation of defect shape. The method is widely used at controlling of thick-walled articles, when high confidence of vertically oriented plane-like defects revealing is required.

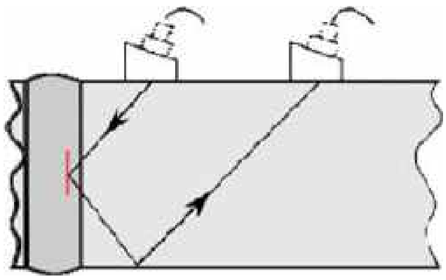


Fig. 7.8. Scheme of inspection by echo-mirror method

Methods of ultrasonic defectoscopy allow to detect such defects in composites as: delamination and cracks between layers, bubbles gaseous inclusions (porosities), cracks, excess of reinforcement or resin, poor cured resin, changing of reinforcement orientation, shifting of reinforcement, violation of ratio between longitudinal and lateral fibers.

However, as a rule, ultrasonic defectoscopy doesn't allow to determine real dimensions of a defect but detects only reflecting ability of a defect in direction of receiver. These values are correlated between each other but not for all types of defects. Besides, some defects can't be revealed practically by ultrasonic method due to their character, shape or location inside of inspected object.

Air gap between inspected object and ultrasonic transmitter has to be fully absent at introduction of ultrasonic oscillations inside of object. To remove the air gap influence immersion mediums (machinery oil, water, glycerin) are used, but embedding of these liquids make the process of control to be more difficult. Quire viscous contact liquids (to prevent quick leakage out of inspected surface) have to be used at control of vertical and very sloped surfaces.

To control articles with outer diameter less than 200 mm one has to to implement transmitters with radius *R* of heel curvature equal to (0.9…1.1)R of radius of inspected object. These transmitters is knows as lapped faces transmitters, which can't be used for inspection of articles with flat surfaces.

Fig. 7.9. Inspection of metal and non-metal adhesive honeycomb structures

To increase resolution ability of ultrasonic method for composites inspection nowadays engineers implement widely so-called computational ultrasonic tomography. The system used guarantees layer-by-layer and multi-position observation of a defect that allows to exclude majority of factors which make defect revealing by conventional method of ultrasonic inspection to be very difficult. Software of the system ensures recording of information, preliminary analysis of results, revealing of defected sections, composing documental reports, drawing images of expanded picture and printing parameters of defects (Fig. 7.9).

Equipment

Nowadays there are many different ultrasonic defectoscopes. They are widely used in all branches of national economy because allow to solve problems of defectoscopy and thickness measuring with high quality. Fig. 7.10 shows universal multi-functional multi-regime defectoscope BondMaster™1000e+ for detection of composites quality. It allows to operate in separate, combined, resonance and impedance regimes. The device has possibility to select optimal option for conduction inspection of different composite materials.

Fig. 7.10. Defectoscope BondMaster™ 1000e+

It can be used for conduction inspection in large production facilities, during objects operation, at the stage of maintenance and repair of composites due to its high-level operational characteristics in combination with low weight and strong case. Changeable screens allow to get high-quality imaging. Colored or monochromic LCD screens are applicable indoors and outdoors at bright sunlight. Electric-luminescent screen is used both at normal and poor lighting. The device is simple in usage and unique by technologies and sets of functions. BondMaster 1000e+ uses technology PowerLink for automized adjusting at joining gages to it. Embedded regimes of calibrations allow operator to optimize parameters of inspection. Large variety of measuring gages are suggested for each method of inspection.

Fig. 7.11 shows low-frequency ultrasonic defectoscope УД2Н-ПМ (uses frequencies from 20 kHz to 2.5 MHz). It is developed for detection of defects (discontinuities inside material) in semi-finished article sand ready products made of composites, plastics and in materials with high level of ultrasound damping, for measuring depth and coordinates of defects location, velocity of distribution and damping of ultrasonic oscillations. It is possible to conduct inspection by means of contactless transmitters which operates through air. The device allows to realize different technics of inspection – with analyzing not only signal amplitude but also frequency spectrum or phase components of a signal.

Fig. 7.11. Low-frequency ultrasonic defectoscope УД2Н-ПМ

Checking-up problems

1. How inspection of quality is conducted by ultrasonic method?
2. What restriction of the method one has to consider at composites quality inspection?
3. What defects can be revealed by ultrasonic method?
4. What equipment is used for ultrasonic defectoscopy of composites?
5. What does it mean resolution capability of the method of ultrasonic defectoscopy? What does it mean maximum and minimum depth of scanning? How can we reduce «dead zone»?
6. What is the essence of echo-method of ultrasonic defectoscopy? What parameters does sensitivity of echo-method depend?
7. Main distinctive features of shadow method of ultrasonic defectoscopy.

7.3. Ultrasonic thickness measuring of article made of composites

One of the main important parameters of composites is their thickness. Thickness less that required leads to reduction of article load-carrying ability. Elevated thickness leads to ungrounded increasing of mass and reduction of specific properties. Therefore, limits of required thickness variation are always designated in technical requirements on composites manufacturing documentation. Generally, thickness variation from nominal values should not exceed ±2…3 %.

Different methods of inspection can be used for determination thickness of skin, web, wing spar cap and other structural elements: infrared, electrical, eddy current, magnetic, ultrasonic etc. The method of ultrasonic thickness measuring is widely used in engineering.

Three main types of inspection can be distinguished at thickness measuring:

1) manual inspection of articles with smooth equidistant surfaces;

2) manual control of articles with rough non-parallel surfaces, for example, articles internal surface of which is damaged by corrosion;

3) automized inspection in flow of articles.

High precision of measuring is necessary for conduction of inspection (1) and (3). Inspection of type (2) requires high sensitivity to catch reflection from non-smooth opposite surface and determine places of maximum local thinning of walls. At automized inspection one has to ensure high measuring volume and control that thickness changing doesn't overexceed limits of given allowance. Types of inspection at thickness measuring can be significantly different, therefore, all of them are conducted with application of different methods of measuring and thickness measuring devices.

Echo-method is the main way of thickness measuring. It is used at conduction of all three methods of detection.

Resonance method is used for inspection of articles with relatively smooth surfaces. Thickness changing at zone of measuring hasn't exceed 8 %, moreover, average thickness is measure but not the minimal one. Error of measuring not less than 2...5 %.

Spectrum method is based on analysis of wideband impulse spectrum changes at passing through inspected layer or article. This method is less precise that resonance one. Spectrum method is useful for automized control conduction. This method can be used for measuring thickness of protective coating on article surface.

Impulse echo-method and resonance methods are generally used for thickness measuring.

Impulse and ultrasonic thickness measuring devices measure the time necessary for ultrasonic impulse to pass up to opposite surface of inspected method, signal reflection from this surface and returning back to receiver. It is more efficient to use this method if opposite surface of inspected object is low-accessed or fully without access because the method doesn't require any access to opposite side. This method allows to measure thickness of majority of such structural materials as metals, plastics, ceramics, composites, epoxy resin and glass and also thickness of liquid layer.

Since ultrasound has poor distribution in air small amount of contact liquid is applied between transducer and surface of inspected object. Generally, glycerin, poly-propylene glycol, water or oil are used as contact liquid.

Ultrasonic impulse, sent by transmitter, passes through inspected object, reaches opposite surface, reflects from it and returns to converter. Like echo sounder thickness measuring device measures time interval between sending sounding impulse and reflected echo signal (usually it takes several micro-seconds). Necessary value of thickness can be found as $d=vt/2$, where t – duration of ultrasonic impulse distribution in inspected object.

Determination of ultrasound velocity is one of the major part of such calculation. Different materials pass ultrasonic waves with different velocity. Moreover, in some materials, especially in plastics, velocity of ultrasound changes at temperature changing. Therefore, set-up of ultrasonic thickness measuring device on correct velocity of ultrasound in object material is very impotent stage of measuring. For this purpose, special reference specimens with known thickness are used.

At any process of thickness measuring selection of thickness measuring device and transmitter depends on inspected object material, range of thickness, required precision. Moreover, one has to consider shape of inspected object, its temperature and other specific conditions.

Resonance thickness measuring devices are used mainly for measuring thickness of articles made of metals, glass, ceramics, composites (at single side access) and for revealing of delaminations etc. The method is based on excitation of ultrasonic oscillations through thickness of inspected article wall and determination of frequencies at which resonances occur.

Standing waves appear in restricted medium due to interference of direct and reflected waves. Appearing of standing waves is possible in case of resonance, i.e. coinciding of outer disturbing force frequency with frequency of proper system oscillations. Fig. 7.12 shows scheme of resonance defectoscope for thickness measuring.

In resonance defectoscope for thickness measuring frequency-modulated generator 1 excites piezo-electric transmitter, which sends ultrasonic waves of continuously variable frequency to inspected object 7. At definite moment, when integer quantity of semi-waves coincides with inspected article thickness, standing waves appear (Fig. 7.13).

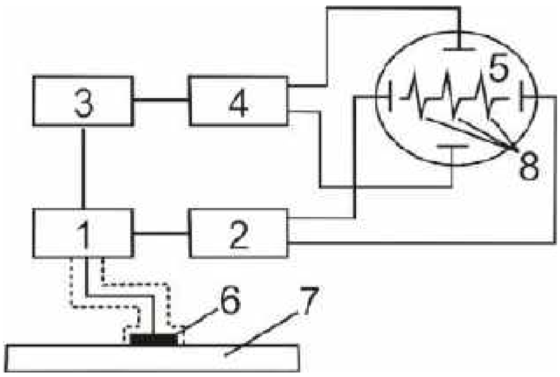


Fig. 7.12. Scheme of defectoscope for measuring thickness: 1 – generator of frequency-modulated oscillations; 2 – sweeping generator; 3 – filter; 4 – amplifier; 5 – EBT screen; 6 – probe; 7 – inspected object; 8 – resonance pikes

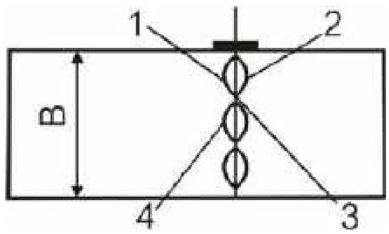


Fig. 7.13. Scheme of standing wave appearance in the wall of inspected object: 1 – direct wave; 2 – reflected wave; 3 – inter section point of waves; 4 – wave loom

1. In simplest case, when inspected object is a plate with free both opposite surfaces, the condition of elastic resonances exciting can be written as

$$h = n\,\lambda/2 = n\,c/(2\,f_n),$$

where f_n – frequency which corresponds to harmonic *n.* It can be seen from the formula that for measuring thickness of an object made of material with known sound velocity passing one has to know resonance frequency and number of oscillation harmonic.

There are two types of industrial resonance thickness measuring devices: for measurements and for adjusting.

Thickness measuring devices are used for direct measuring of an article wall thickness *h* at definite points when required value of h is unknown. Frequency variation in such devices has to be enough to overlap wide range of thicknesses. Moreover, special registering devices have to be involved to measuring to determine quickly absolute values of h. Error of measuring can reach 2…5 %.

2. Reference thickness measuring devices are involved to technological cycle to prevent overexceeding of article wall thickness required allowance. Wall thickness is known; therefore, frequency deviation can be selected to be relatively small that increases sensitivity and precision of measuring. Labor-production and precision of reference thickness measuring devices is more than ordinary ones because they use immersion contact to input ultrasonic oscillations to

inspected object and precision is 1…2 %.

By method of elastic oscillations transmission following devices can be distinguished:

– contact;
– immersion;
– contactless.

By design thickness measuring devices can be:

– portable with autonomous power supply (for inspection in field conditions);
– movable (for measurements in shop conditions);
– stationary (for automized and semi-automized inspection devices).

Equipment

Ultrasonic thickness measuring device ТУЗ-1 (Fig. 7.14) is developed for measuring thickness of different articles at condition of single-side access. It can be used for all branches of industry for measuring thickness of pipings, pressure vessels, boilers etc and other responsible and especially dangerous objects and allow also to determine degree of corrosion and erosion wear by value of residual thickness. Thickness measurement device ТУЗ-1 has following technical characteristics:

– range of measuring (by steel) – 0.6...300 mm;
– resolution capability - 0.1 mm;
– range of ultrasound velocity set-up - 0...9999 m/sec;
– capacity of internal memory - 2400 measurements;
– range of operational temperatures - -20 ...+50 °C;
– overall dimensions 164x84x30 mm;
– mass 0.4 kg.

Fig. 7.15 shows ultrasonic thickness measuring device УТ-31 developed for measuring thickness of articles made of metal and non-metal materials at single access to them for inspection in the process of articles manufacturing, maintenance or repair in different industry branches.

Large number of different transmitters ensure wide range of thicknesses measure (from 0.8 to 200 mm).

Fig. 7.16 shows high-precision thickness measuring device with A-scan УДТ-40. It possesses high precision and reliability of inspection. Presence of A-scan excludes such typical errors like twinning of readings. B-scan allows to observe an article bottom geometry.

Ultrasonic transmitters for thickness measuring

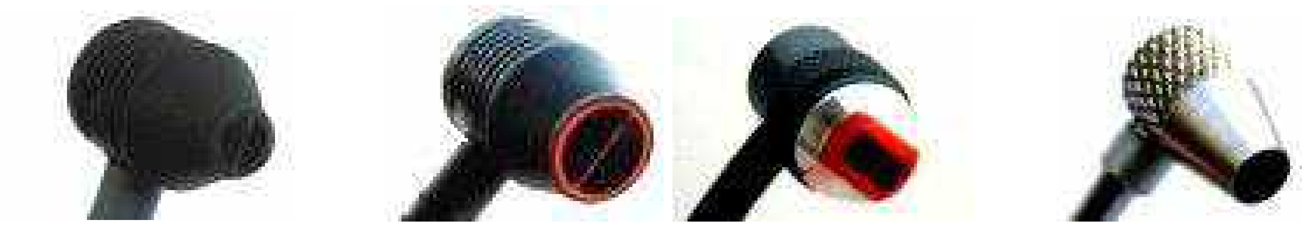
Standard transmitters of 01 series (Fig. 7.17, *a*) are developed for solving typical problems of measuring.

Transmitters of 02 series (Fig. 7.17, *b*) are developed to measure article thickness in expanded range. They ensure better near-surface resolution at inspection of thin-walled corroded articles.

Fig. 7.14. Ultrasonic thickness measuring device ТУЗ-1

Fig. 7.15. Ultrasonic thickness measuring device УТ-31

Fig. 7.16. High precision thickness measuring device with A-scan УДТ-40



a b c d

Fig. 7.17. Ultrasonic transmitters for thickness measuring

Transmitters of 04 series (Fig. 7.17, *c*) are low-dimensional transmitters, specially developed for measuring thickness of low-dimensional articles and measurements at places with poor access (turbine blades, wing spars, low diameter tubes), and also in places which require high resolution (localization or small spot or contact).

Transmitters of T-01 series (Fig. 7.17, *d*) are high-temperature transmitters for measuring residual thickness of articles operating at high temperature (up to 350 °C). Transmitters possess high thermal stability of properties due to application of special materials. Transmitters have different contact surfaces that allows to inspect articles of different shape.

7.4. Inspection of composite materials quality by means of the method of free oscillations

The method of free oscillations is the method of non-destructive inspection based on exciting of free damping elastic oscillations inside inspected object or its part and consequent analysis of oscillations parameters.

Methods of non-destructive testing based on measuring of proper (eugen) frequency are widely used last years. They can be divided on methods of free oscillations, methods of induced oscillations, which in their turn are divided on local and integral methods of inspection.

Method of free oscillations was used many years ago. Quality of pottery wares (presence of cracks and other defects) was determined by blasting sound, created by ceramic ware at rapping.

Nowadays this method is used widely at selling of glass wares. This method is also used in railway engineering, when walking inspector raps by special hummer definite elements of train carriage at standing post of railway station, trying to detect defects which can lead to emergency situation.

Methods based on measuring frequency of proper oscillations can be used for determination physical-mechanical properties of material and articles. For example, for determination of one of the main characteristics of elastic material properties, i.e. Young's (elasticity) modulus. The method of induced oscillations for determination of elasticity modulus was originally used by English engineer Tomas Young.

The essence of the method of free oscillations is in following: oscillations artificially induced in solid damp with time, elastic energy of oscillations dissipates converting to heat energy due to internal friction.

The method of free oscillations is based on recording of energy dissipation in structural material. If defect is presented in detecting body parameters of oscillation system are changed that leads to changing of amplitude, proper oscillation frequency and logarithmic decrement of oscillations damping. As a result, one can get vibrograms of free oscillations. By the rate of vibrograms decreasing values of relative energy dissipation or logarithmic decrement of damping can be determined (Fig. 7.18). Logarithmic decrement of damping can be calculated by vibrogram of free oscillations for testing body:

$$\delta = ln\ (Ai/\ Ai+1).$$

The method of free oscillations is used for inspection of multi-layer, neonmetal and composites. It allows to detect porosities, faulty of adhesive joints, delamination, violation of bonding rigidity between layers.

If exciting elastic oscillations are applied to an article with definite dimensions, shape, mass, rigidity then parameters of free damping oscillations can be possessed for exact article. Practical application of the method can be restricted by strong dependence of proper oscillations frequency on shape and dimensions of inspected object. However, successes reached in spectrums of proper oscillations frequency for articles of different shape and dimensions and application of computers allow nowadays to simplify inspection procedure. Finally, engineers can to use the method in different cases.

There are several methods of impact exciting of elastic oscillations in inspected object: mechanical (electro-mechanical), piezo-electrical, electromagnetic-acoustic etc.

Mostly, electro-mechanical method is used. Special movable electro-magnetic mechanisms, which create oscillations in inspected body, are used in the method.

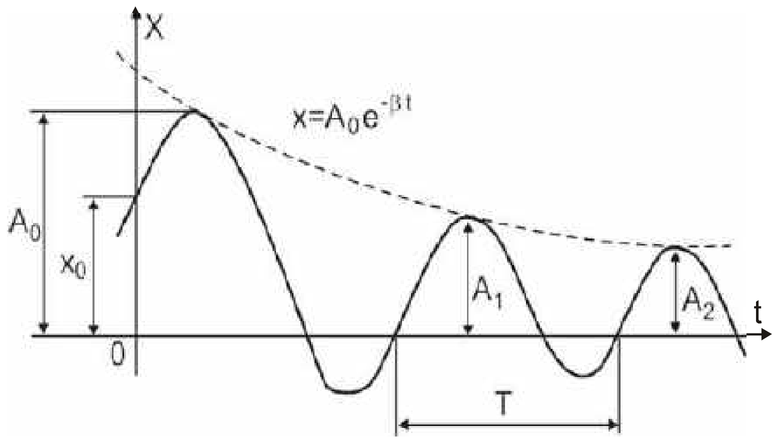


Fig. 7.18. Damped oscillations of a system

Signal receiving is conducted by microphone (Fig. 7.19, *a*) or by piezo-receiver (Fig. 7.19, *b*). Piezo-receiver is less dependable on interference but it is auxiliary source of disturbance on inspected object.

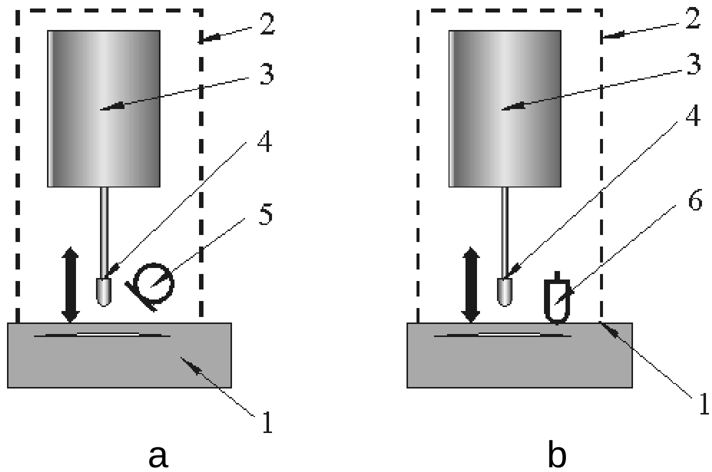


Fig. 7.19. Structural scheme of defectoscope: a – with microphone receiver; b – with piezo-electric receiver; 1 – inspected object; 2 – case of transmitter; 3 – electromagnet; 4 – movable system; 5 – microphone; 6 – piezo-receiver

At application of transmitters with electromagnetic impactor and microphone receiver impactors contacts with inspected article for a short time. After that transmitter has no influence on character of free damping oscillations. Therefore, spectrum of free damping oscillations is defined by parameters of inspected object only. Impact transmitters are better that piezo-electric ones at inspection of articles made of material with low elasticity moduli or lightweight (for example, foam plastic) fillers. Application of several transmitters of different types can wider capability of defectoscope.

Equipment

To realize method for industrial application engineers use special devices for proper frequency measuring like "Звук" of two modifications: devices based on resonance method - "Звук-107" (Fig. 7.20) and devices based on the method of free oscillations - "Звук-203" (Fig. 7.21).

Device "Звук-203" doesn't allow to inspect low-dimensional articles. To inspect such articles the method of induced oscillations is recommended. It is implemented in the device "Звук-107".

Device "Звук-203M" – is portable device kept in the palm by operator. It is supplied by inner electret microphone to receive acoustic oscillations, with LCD display to indicate measuring parameters and film keyboard to control device.

Fig. 7.20. Device «Звук-107»

Fig. 7.21. Device «Звук-203»

Practically momentary after making impact on inspected object surface one can see result of measuring on screen in predefined option: proper oscillations frequency, reduced velocity of acoustic waves distribution, physical-mechanical properties, for example, Young's modulus, strength, density, porosity and other by means of device setting-up with correspondent correlation and analytical dependences. Power supply can be done by both batteries and power supply network. It is possible to communicate with PC by RS-232.

Devices "Звук" work together with PC. Device "Звук-110M" consists of measuring arm and electronic motherboard of PC. Measuring is conducted automatically after attaching of inspected object to measuring arm and launching special program, which analyze spectrum of proper oscillation frequencies. Results of measuring after processing can be shown on display and store in database.

Also engineers use foreign defectoscopes "Grindo Sonic" produced by Belgium firm "J.W. Lemmens N.V.".

Advantage of the method of free oscillation is simplicity of measurements conduction.

Disadvantages of the method:

– low resistance to interference;
– impossibility of inspection of objects made of materials with high damping of ultrasonic sound.

Checking-up problems

1. How to conduct quality inspection by the method of free oscillations?
2. What defects can be revealed by the method of free oscillations?
3. What are main advantages and disadvantages of the method of free oscillations.

7.5. Method of acoustic emission

The method of acoustic emission is widely used both at the stage of composite articles testing and at the stage of inspection during operation and repair.

Method is used for analysis of crack-appearing processes in articles. It is based on studying acoustic parameters (intensity of acoustic impulses, amplitude and frequency spectrums etc) at appearing of micro-cracks in articles under loading, level of which significantly less than ultimate (breakage) value.

The goal of acoustic emission is revealing, determination of coordinates and monitoring of acoustic emission sources.

Phenomenon of acoustic emission is in following: elastic waves are radiate by material due to dynamic local re-arrangement of its structure. At any outer influence energy, given to a material, leads to structural transformation at definite value of this energy. In metals such structural transformations related to plastic deformation (dislocations movement) and with process of cracks appearing. Therefore, main source of acoustic emission in metals is plastic deformation and cracks distribution. The most typical sources of acoustic emission in composites are cracks developed under outer loading. It is more difficult to reveal defects in composites by the method of acoustic emission because elastic waves appear both in matrix, reinforcing materials and zones of contact between matrix and reinforcing material which frequently have micro-discontinuities. Quality inspection of composites shows definite difficulties related to complexity of results of inspection analysis because waved process of acoustic emission is accompanied by parasitic acoustic parameters of multiply reflected waves.

Technical diagnostics of objects by the method of acoustic emission is conducted at stresses structure only. Stress structure initiate in object material work of acoustic emission sources.

Sources of acoustic emission can be divided by four classes:

1) passive, which are registered for further analysis of dynamics of development;
2) active, which consequent inspection is strongly recommended;
3) critically active, which require urgent repair measures;
4) catastrophically active, at presence of which the structure must be

momentary put out of operation.

Oscillations are distributed from the source to gages where they are transmitted to electrical signals. Devices of acoustic emission register these signals and image data on the screen as oscillograms, locations, digital indications. Based on these data operator can estimate state and behavior of material structure ubder loading, detect and reveal location of defects (Fig. 7.22). By registered duration t_i of signal passing to i-th receiver (gage) system can determine time difference t ($t = t_2 - t_1$) of signal getting two separate receivers. Then coordinates of a source (defect) can be calculated by known velocity of sound in inspected material and known coordinates of receivers using special software.

Transmitter of acoustic emission converts elastic acoustic oscillations to electrical signals and is one of the most important elements of hardware complex (HC) of control. Mostly piezo-electric transmitters (PET) are used. Their electrical scheme is the same like in PETs used in ultrasonic inspection.

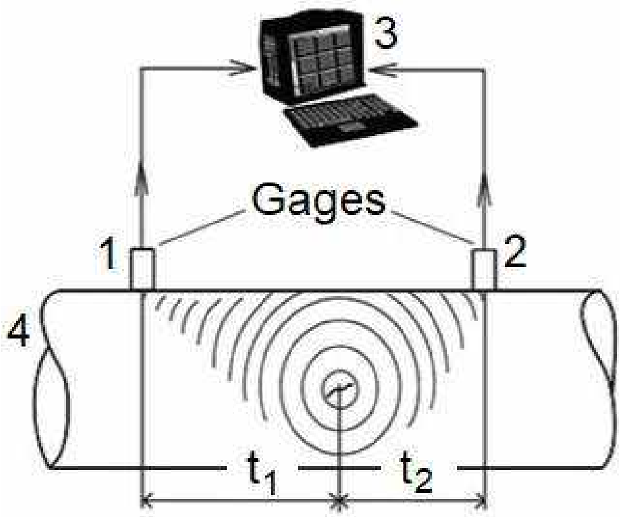


Fig. 7.22. Scheme of defect inspection by the method of acoustic emission: 1 – HC transmitter (receiver 1); 2 – HC transmitter (receiver 2); 3 – central block of receiving and analysis based on industrial computer; 4 – inspected object; t_1 – duration of signal passing to the receiver 1; t_2 – duration of signal passing to the receiver 2

Since material structure defects are sources of acoustic emission, one can assume that coordinates of source of acoustic emission and coordinates of defect are equivalent. However, it is necessary to consider that defects have definite spatial configuration and dimensions, i.e. coordinates of source of acoustic emission are define the point in material at neighborhood of which defect is developed.

Determination of coordinated of acoustic emission sources is based on radiolocation. Developing defect radiate impulses of acoustic emission to ambient space. Measuring parameters of these impulses allow to determine location of a sources by means of separated transmitters. Amplitude of signals and duration of signal passing evidence about defects location (close defect to transmitter higher signal amplitude). Engineers mostly apply methods in which dependence of signal passing duration to separate transmitters is used.

If inspection for exact articles is conducted first time by method of acoustic emission it is necessary to conduct series of preliminary testing to select proper measuring regime of devices, estimate suitable criteria for faulty articles, find temporary interval for registration, durational interval for testing, select zone of inspection and type of intermediate medium. At inspection stage operator has to create the same conditions of stressed state as in real operation. Preliminary testing is conducted up to final failure of inspected object with recording parameters of acoustic emission. After object failure fractographic measurements of flaw rate of development and its length is conducted by means of electronic microscopy. Then got results are compared with experimental ones. Since the process of flaw appearance is exactly related to material failure kinetics the method allows to estimate an article state in operational conditions (if observe the process of flaw appearance in dynamics).

Equipment

Fig. 7.23. System Малахит AC-15A

Up-to-date digital devices and multichannel systems of acoustic-emission control "Диатон" possess high reliability, comfortable user interface. Apparatus, sets of acoustic-emission transmitters, standard and specialized software allow to inspect any objects by means of the method of acoustic emission (Fig. 7.23).

Advantages of the acoustic emission method:

1. It allows to inspect entire object as a whole by means of one or several gages, installed unmovably on the object surface. As a result, the method can inspect surfaces of inspected object with restricted access and surfaces without access at all.

2. In comparison with scanning methods of non-destructive inspection, the method of acoustic emission doesn't require preparation surfaces of inspected object. Therefore, results of inspection don't depend on surface state and quality of treatment.

3. The method allows to detect and record defects which begin to develop only, that permits to classify defects not by their dimensions (or by other indirect features, i.e. shape, location, orientation), but by their degree of danger (to material strength influence) for inspected object.

4. Location and orientation of inspected object don't affect defects revealing.

5. High production volume of the method, more than ultrasonic and radiographic and other methods have.

6. Remoteability of the method of acoustic emission is possibility if inspection conduction at significant operator remoting form studying object, that allows to use the method effectively for inspection of large-dimensional structure without structures shutting down.

7. Possibility to observe different technological processes and estimate technical state of an object in process of operation that allows to prevent failure

of controlling object.

8. High efficiency of the method.

Distinctive feature of the method of acoustic emission which restricts its application in some cases is selection of revealing signals of acoustic emission from accompanying interference signals. Therefore, when signals of acoustic emission are relatively low by amplitude, it is quite difficult problem to separate useful signal from interference.

All indications caused by sources of acoustic emission are more effectually to estimate by other methods of non-destructive inspection. The method of acoustic emission can also be used for estimation rate of defect development to stop testing beforehand and prevent article failure.

The method of acoustic emission allows to get large arrays of information, regulate and prolong operational cycle of responsible industrial objects quickly and with minimal expenses. It allows to predict possibility of emergency failure and catastrophes occurring. The method also suggests wide possibilities for studying properties of different materials and structures.

Checking-up problems

1. What is the essence of the method of acoustic emission? In what cases it is more effective to apply the method?
2. What defects can be revealed by the method of acoustic emission? What principle does their revealing based on?
3. What is the distinctive feature of the method of acoustic emission application at inspection of composites?
4. What are main advantages and disadvantages of the method.
5. How to determine coordinates of sources of acoustic emission?

7.6. Inspection of multi-layer composite structures by impedance method

Impedance method belongs to acoustic methods of non-destructive inspection in in some cases can ensure quality inspection of articles with flat and curved surface allowing to find delaminations, faulties of adhesion, poor adhesion, degree of polymerization.

The method is based on elastic oscillations exciting in inspected object and analysis of mechanical impedance changing at zone of defect comparing with one measured for good quality zone by means of movement of transmitter over article surface.

Mechanical impedance or total mechanical resistance Z (the force of an object reaction) is ratio of exciting force F to oscillating velocity V (caused by this force) of medium particles at zone of force application:

$$Z = F/V.$$

Mechanical impedance is the parameter of a structure, i.e. for multi-layer structures mechanical impedance at zone of exciting force application is defined for all elements of the structure joined to entire mechanical system.

At defectless zone of an article impedance is defined by all layer of structure which oscillates as a total object, moreover, its modulus is quite high value $|Z_1|$. If structure contains such defects as delaminations, faulties of adhesive joint etc then impedance of defect zone $|Z_2|$ will be less than impedance at defectless zone $|Z_1|$. It relates with following: if gage is disposed above the delamination then part of damaged skin will oscillate as a plate clamped by contour and this plate doesn't connected rigidly to entire structure. Therefore, reaction force will be significantly less. In such case shifting of phase occurs between received signal and voltage after exciting generator. This is evidence about presence of defect and its parameters (Fig. 7.24).

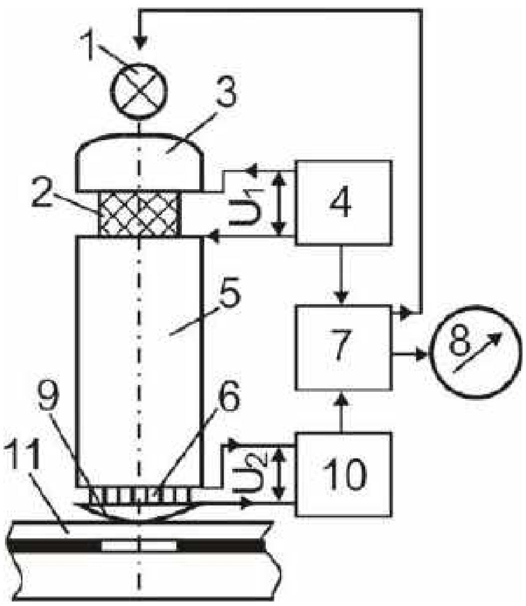


Fig. 7.24. Structural scheme of impedance defectoscope: 1 – signal lamp; 2 – piezo-element with generates oscillations; 3 – weight (to increase power of signal sent to a rod); 4 – generator; 5 – rod; 6 – measuring piezo-element; 7 – block of signal processing; 8 – indicator; 9 – contact tip with spherical surface; 10 – amplifier; 11 – inspected object

Ultrasonic microscopes with transmitters are used to estimate changing of mechanical impedance. Transmitter is a rod 5, at edges of which two piezo-elements are disposed: one for oscillations exciting 2 and for measurements 6.

Between inspected object 11 and piezo-element 6 contact tip 9 with spherical surface is disposed. This tip measures value of mechanical impedance at defectless and defect zones of inspected object. Piezo-element 2 jointed with generator 4, which applies voltage U_1. Piezo-element 6 receives changing of mechanical impedance of a total system. In this piezo-element mechanical oscillations ate converted to voltage U_2, which passes to amplifier 10, and then to registering device 8. Mass 3 increases power of emission to the rod 5. Generator and amplifier are connected with the block of signal processing 7 and with indicator 8 at the end of the circuit. Block 7 controls signal lamp 1 and self-recording device which registers defects at application of defectoscope in the systems of mechanized inspection.

Equipment

Portable impedance defectoscope ДАМИ-С (Fig. 7.25) is developed for finding defects in composites and honeycomb structures and revealing corrosion in non-ferromagnetic alloys in different aviation structures. Transmitter adjusts automatically to inspected object considering its density and material structure.

Impedance defectoscope ИД-401 (Fig. 7.26) is developed for composites inspection. It allows to reveal defects like delamination, faulty of adhesive joining, discontinuities inside inspected material. It can be used in laboratory, industrial and field conditions.

Fig. 7.25. Universal defectoscope for composites ДАМИ-С

Fig. 7.26. Impedance defectoscope ИД-401

Impedance defectoscope ИД-91М (Fig. 7.27) is developed for inspection of delaminations, falties of adhesive joints in articles made of laminated plastics and composites.

It is used at production and maintenance of aerospace objects. Two types of transmitters are used in the method: combined (SP) и separated-combines (RSP). Minimal dimension of a defect revealed in composites by combined transmitter is 5 mm.

Fig. 7.27. Impedance defectoscope ИД-91М

By means of defectoscope ДАМИ-С one can conduct quality inspection of laminated structures mad of non-metal materials (carbon plastic, glass, plastics, textolites), honeycomb structures with non-metal facesheets and honeycomb made of polyamide paper or other materials, honeycomb structures with metal facesheets (including perforated) and honeycombs, structures with different fillers, laminated adhesive structures (with two, three and four layers), rough honeycomb and other structures with regularly changeable impedance of a surface and (or) variable thickness, sheet structures made of non-ferromagnetic materials.

Maximum depth of defects revealing in composite articles with separated-combined transmitter is 13 mm (in structures made of aluminum alloys with thickness up to 3 mm), by combined transmitter – 4 mm (1.5 mm).

Impedance express-tester ТЭРИ (Fig. 7.28) is developed for application in civil aviation and used for impedance express-inspection of multi-layer soldered, adhesive composites and structures with honeycombs and permits to find defects like delamination and faulty of adhesive joint. ТЭРИ belongs to the group of devices of indicating type and is not the mean of measurement. ТЭРИ is simplified modification of the defectoscope ДАМИ-С and fully adjustable with used PET. The device is simple in operation and setting-up.

Fig. 7.28. Impedance express-tester ТЭРИ

At inspection in field conditions, it is necessary to change inspected materials frequently the adjusting of device has to be as simple and quick as it possible. Device ТЭРИ can set it up automatically. One has to dispose it on defectless zone and device will select necessary values of measuring to signalize about defects presence. It is possible to conduct manual setting-up. In operation the device is attached with special strip to an arm of operator that increases movability and comfortability of measurements.

ТЭРИ is used in civil aviation as up-to-date alternative of such previous generation inspection method as mechanical knocking of honeycomb structures. ТЭРИ allows to increase objectivity and reliability of inspection.

Operational standard specimens (OSS) are used for setting-up of defectoscopes and selection of optimal regimes. OSS as a panel with dimensions 300x300 mm is used for sandwich structures inspection. Panel consists of facesheets and honeycomb filler. Defects in panel are simulated by means of creation round pits with diameter 30, 20 and 10 mm, depth is 3 mm. Materials of facesheets/honeycomb and technology of OSS manufacturing have to be the same as materials and technologies of real article manufacturing.

Impedance method is used for inspection of adhesive assemblies including sandwich structures with metal and non-metal skins and light fillers (honeycomb, foam plastics). Also, delaminations is article made of laminated plastics can be revealed.

Sensitivity of acoustic impedance method depends on rigidity of skin or separate defect layer; elasticity modulus of inner structural element; ratio of skin rigidity and rigidity of entire structure; roughness and curvature of inspected object surface.

Sensitivity of impedance method is restricted by scattering of mechanical impedances at defectless zones and depends on non-constant thickness of adhesive film, inhomogeneities in article, which are not features of article poor quality but lead to interference appearance. This interference creates negative background which makes revealing of fine defects to be more difficult.

Elastic resistance of contact zone of transmitter with an article reduces transmitter sensitivity to changing mechanical impedance of a system. Elastic resistance is stipulated by low area of contact of transmitter tip with inspected object.

Disadvantage of the method – it is possible to reveal defects which are located at relatively low depth.

Checking-up problems

1. What is the essence of impedance method of quality inspection?
2. What kind of composite articles does the method allow to reveal?
3. What defects can be revealed by impedance method?
4. What equipment is used for composites defectoscopy by impedance method?
5. What parameters does sensitivity of impedance method depend on?

8. DETERMINATION CHARACTERISTICS OF COMPOSITES BY ELECTRICAL METHOD

Many polymeric materials belong to dielectrics by their electrical properties.

Four following physical processes occur and develop under electric field influence: polarization, electrical conductivity, losses of electrical power (dielectric losses) and dielectrics breakdown.

Ability of dielectrics to conduct electrical current is estimated by the value of volumetric specific resistance ρ_v.

Ability of dielectric to polarization under electrical field is characterized by dielectric permeability ε. More intensive polarization process more value of ε.

Power dissipated in dielectric is known as dielectric losses. The value of dielectric losses is generally estimated by the tangent of an angle of dielectric losses $tg\delta$.

Dielectric breakdown is phenomenon of through the thickness electrical conductivity appearing in a material under influence of electrical field with definite intensity. Intensity of electrical field at which breakdown of dielectric with unit thickness occurs is known as electrical strength E_{red}.

Each of above-mentioned characteristics is quite sensitive to changing of composite structure, moisture absorption by material, appearing of different defects (porosities, cracks, delaminations etc) in composite. Therefore, dielectric characteristics can be used for composites quality control inspection both during manufacturing and for revealing of different defects in ready articles and structures made of composites.

Dielectric permeability ε and tangent of dielectric losses angle $tg\delta$ are especially sensitive to changing of composite structure, violation of ratio between resin and reinforcing material, presence of moisture, appearance of porosities, cavities, faulties of adhesion and other defects.

Exactly these two characteristics of composite are most frequently used for both control of composites manufacturing process and inspection of ready composite articles.

Under influence of electrical field composite article polarization occurs, i.e. process of restricted shifting and orientation of bonded electrical charges. Value of relative dielectric permeability can be found by formula

$$\varepsilon = C_d/C_0, \qquad (8.1)$$

where C_d – capacity of a capacitor with composite medium; C_0 – capacity of a capacitor without composite medium (in vacuum).

Relative dielectric permeability of composites is always more than one.

Since composites are heterogeneous structures, different types of polarization occur inside of them, stipulated by properties of components and material structure.

There are following types of polarization mechanisms: electronic, ionic, dipole-relaxation, ionic-relaxation, electronic-relaxation, migrational (structural), spontaneous etc.

Electronic and ionic polarizations relate to momentary ones with short stabilization time ($10^{-15}…10^{-13}$ sec). These two mechanisms of polarization occur elastically and don't accompany with energy dissipation.

Electronic polarization related to elastic shifting and deformation of electronic shells of atoms and ions. This type of polarization occurs in all dielectrics.

Ionic polarization is related to shifting of bonded ions on distance less than lattice period in solids with ionic arrangement.

Other mechanisms of polarization belong to slow ones and are always accompanied by energy dissipation.

Dipole-relaxation polarization is related to partial orientation of dipole molecules under electrical field influence (dipole molecules are subjected to chaotical heat movement). Dipoles rotation in accordance with electrical field direction relates to resistance of a medium that leads to energy losses. Dipole-relaxation polarization causes radical rotation with respect to molecule in solid organic compounds.

Ionic-relaxation polarization occurs when poor-bonded ions of substance are transmitted to the spacing more than crystalline lattice period under influence of electrical field.

Structural (migrational) polarization occurs in dielectrics with non-uniform structure to which practically all composites are related.

Dielectric permeability of composites is defined by the nature of original components, composite structure and depends on temperature, material humidity and frequency of outer electrical field.

For example, glass plastics belong to materials in which practically all types of polarization occur. Separately resins possess electronic and dipole-relaxation polarization, but dry glass reinforcement possesses ionic-relaxation polarization. Migrational (structural) polarization are always occurs in composites.

Dielectric permeability of multi-component dielectric (polymer + filler + water + air) ε^k can be calculated by formula

$$\varepsilon^k = \sum_{i=1}^{n} \theta_i \varepsilon_i^k , \quad (8.2)$$

where ε_i and θ_i – dielectric permeability and volume fraction of *i*-th component of a system; n – quantity of components; *k* – coefficient considering particles orientation with respect to field direction. Coefficient k varies from –1 to +1. For orthotropic and transversally-isotropic composites at disposition of capacitor plates along composite layers *k*=-1. In case of capacitor plates orientation across fibers *k*=+1.

If filler is randomly distributed in matrix dielectric permeability can be found by formula

$$\ln\varepsilon = \sum_{i=1}^{n} \theta_i \varepsilon_i \ . \quad (8.3)$$

For laminated double-component medium the formula can be transformed to following view:

– for direction in-plane of layers:

$$\varepsilon = \varepsilon_1\theta + \varepsilon_2(1-\theta) ; \quad (8.4)$$

– for direction perpendicular to layers:

$$\varepsilon = \frac{\varepsilon_1\varepsilon_2}{\varepsilon_2\theta + \varepsilon_1(1-\theta)} . \quad (8.5)$$

Fig. 8.1 shows dielectric permeability frequency dependence. It follows form the figure that more frequency less ε. It can be explained by following: different types of polarization have different relaxation duration which becomes more than duration of electrical field influence. Duration of relaxation is characteristic time during which the quantity of originally oriented particles decreases in *e* times.

It can be seen from the dependence *ε (lg f),* that type of polarization in composite can be determined by *ε* surges at known frequency.

Dielectric losses is energy dissipated in dielectric at influence of alternative field which leads to material heating. There are three main types of dielectric losses:

1) losses on electrical conductivity stipulated by leakage currents due to presence of definite quantity of free charges in dielectric;

2) polarization losses stipulated by slow types of polarization;

3) ionization losses appeared at ionization of gaseous inclusions in composite at high values of electric field intensity $E \geq E_{red}$;

4) losses appeared due to structure non-uniformity.

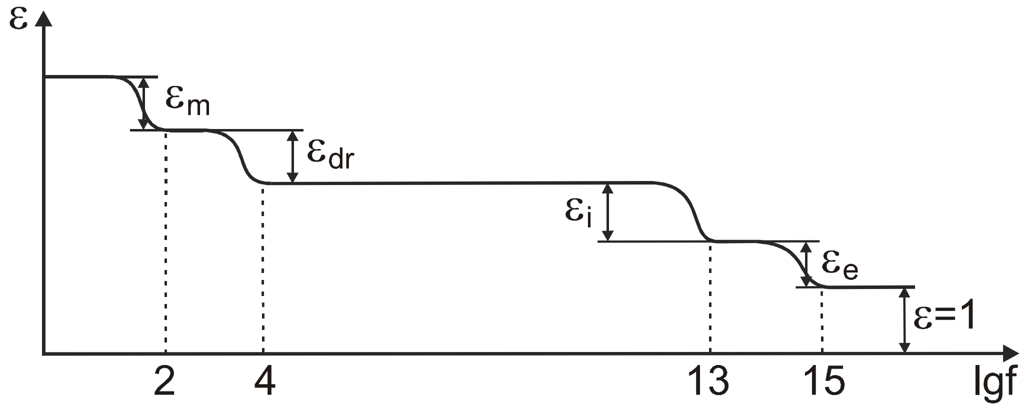


Fig. 8.1. Dependence of dielectric permeability of frequency

Materials with dipole-relaxation and ionic-relaxation polarization possess high losses. Examples of such materials are polyurethanes, ebonite, organic glass, phenolic-formaldehyde resins, epoxy resins, non-organic glasses. All three types of losses can be observed in solid non-uniform dielectrics.

Dielectric losses are characterized by value of specific losses, which are defined as ratio of dissipated power P_a to unit volume of a material, or by angle of losses δ (or by tangent of the angle $tg\delta$).

The angle of dielectric losses δ is angle which adds the angle of phases shifting between current and voltage in capacity circuit up to 90º (Fig. 8.2).

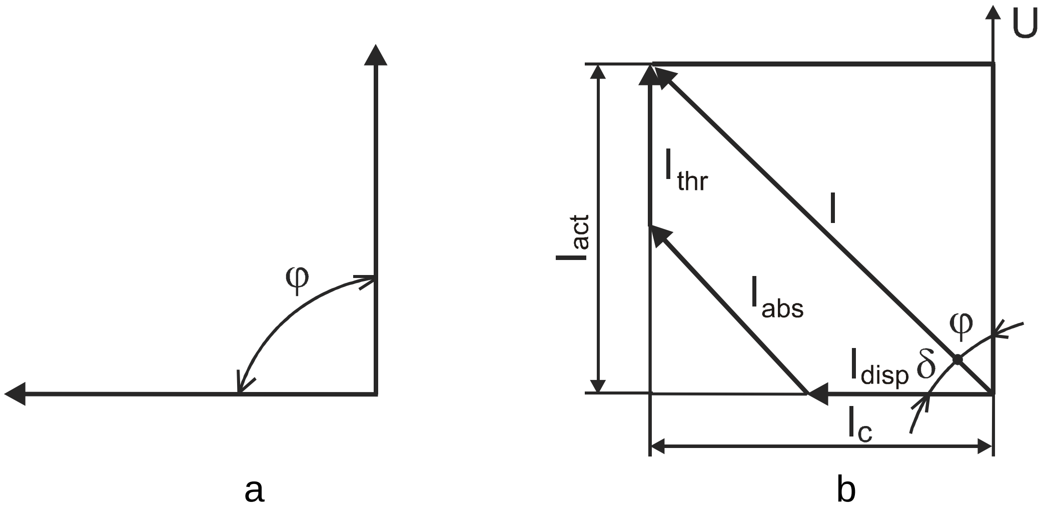


Fig. 8.2. Vector diagram: a – for ideal dielectric; b – for dielectric with losses

Dielectric losses of composite disposed in alternative electrical field can be found as

$$P_a = U^2 \omega C \, tg\delta, \qquad (8.6)$$

where P_a – power dissipated in material; U – voltage; ω – angular frequency of electric field; C – capacity.

The value of tangent of dielectric loss can be determined by known active I_{act} and reactive I_c components of current passing through dielectric:

$$tg\delta = I_{act} / I_c. \qquad (8.7)$$

Like dielectric permeability, the value of величина tgδ depends on composite structure, temperature, humidity, frequency of applied voltage and other factors.

Electrical methods also include the method of electric breakdown, which uses for revealing of through the thickness inhomogeneities or porosities in sheet composites and for revealing of liquation zones in matrix or filler. For inspection of such defects, material is disposed between two plates to which critical values of breakdown voltage is applied. By electric strength of inspected composite one can make conclusion about defects presence inside of it.

Devices and means of measurements

Fig. 8.3. RLC measuring device LCR-800 (by GW Instek manufacturer)

RLC-measurers are used for measuring resistance *R*, induction *L*, capacity *C* (Figs 8.3, 8.4). Main difference of measurers between each other is in a range of testing frequencies. The set of frequencies defines the range of measuring capacities and inductions because the value of complex resistance modulus depends on frequency. In up-to-date measurers test-signal is created by means of technology of direct digital synthesis, that guarantees wide net of frequencies. The value of complex resistance is calculated through values of current and voltage on measured element by means of digital processing. Frequency range up to 1 MHz ensures measuring of capacities from 2 pF and induction from 1 μH.

Fig.8.4. Digital portable RLC-meter AM-3023

Checking-up problems

1. Main distinctions of composites quality inspection by electric method.
2. What type of defects can be revealed by electric method?
3. By what dielectric characteristics quality of composite can be estimated? Which of these characteristics are mostly used for control of technological process of composites manufacturing and for inspection of ready composite articles?
4. What equipment is used for inspection by electrical method?

9. HOLOGRAPHIC INTERFEROMETRY

Holographic method is the method of non-destructive inspection based on analysis of interference image obtained at interaction of reference and dissipated beam of coherent waves emission, which interact with inspected object. Interference is observed at composition of two waves, when typical spatial distribution of light intensity occurs (so-called interference image) at condition of their coherency, i.e. constant waves phases difference. Photographic plate-detector records this image as interlaced light and dark strips (or interferograms).

Holographic defectoscopy is conducted based on registration of article deformable state changing related to defects presence. Regular interference image, created at loading of inspected article, is distorted at defect zones (cracks, cavities, falty of adhesion is laminated structures etc). For example, in case of a crack interference strips at its different sides withstand bent fracture or shear. Loading of inspected article at holographic defectoscopy can be static or vibrational. In some cases article can be subjected to local heating or cooling. At holographic recording of optical information about waved processes lasers are used. Lasers are intensive sources of coherent emission. Fig. 9.1 shows scheme of installation for holograms obtaining.

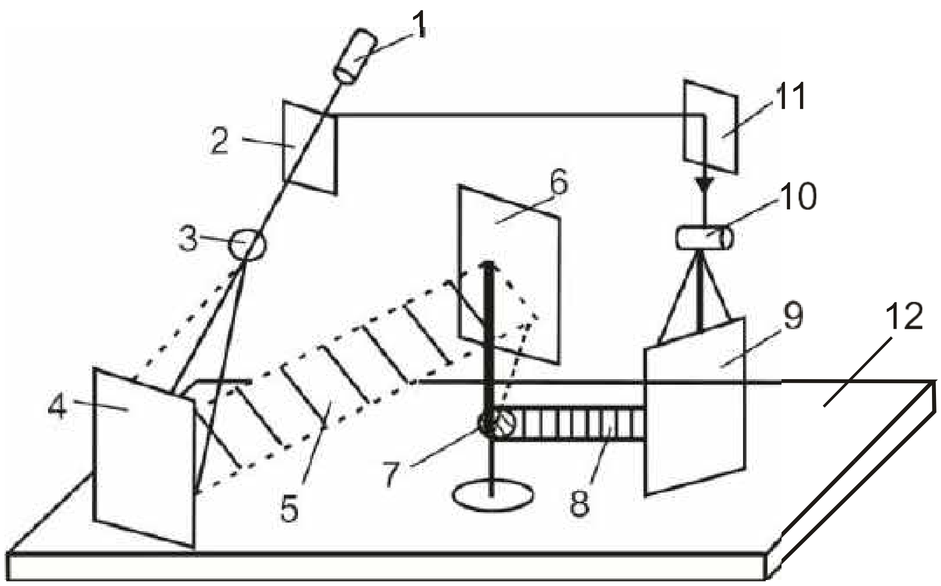


Fig. 9.1. Scheme of holograms created by Leight scheme: 1 – laser, source of coherent emission; 2, 4, 9, 11 – mirrors; 3, 10 – expanding lenses; 5 – reference batch of rays; 6 – photographic plate; 7 – inspected object; 8 – objective batch of rays; 12 – massive basement

Hologram can be obtained due to interference of laser monochromic emission divided by two parts: beam dissipated by holographing object and direct (reference) beam passing to photographic plate leaving out inspected object. Beam of laser 1 is splitted by semi-transparent mirror 2 on two beams. Beam passed through a mirror is known as reference beam. Lens 3 and concave mirror 4 create flat waves inside reference beam. Beams of flat waves pass in parallel to each other. Another beam, which lightens object 8, is known as objective beam. By means of lens 10 and mirror 9 objective beam also expands and lightens object 7.

If object is considered as a point, then waves reflected from it will have spherical shape with the center at this point. If both beams are coherent, then interference picture appears in all volume where beams are overlapped. Light-sensitive medium will change due to light energy influence.

Photographic emulsion is light-shortened more at those places where light waves are strengthen each other, but less at places where waves weaken each other. After film development one can get hologram, i.e. interference picture of interaction between reference and objective beams written oh photographic plate.

Hologram contains all necessary information about object. At recording restoration image on photographic plate is high-lighten by reference beam only. Therefore, one can see two spatial visible images of holographic object – real and virtual.

Holographic interferometry is used for revealing of structural inhomogeneities, cavities, tears, inclusions of other substances, warping, and determination of deformations, deviations from templates, value of which is comparable with wavelength of laser used for measuring. Using hologram one can conduct direct measurements of an object, find coordinates of separate points, study geometry, shape etc. Holographic interferometry allows to register both amplitude and phase information included in wave front. Therefore, it is possible to loot on object from different points of view, take pictures of different object articles, disposed on different distances from researcher.

Advantages of the method:

– contactless;

– high sensitivity;

– possibility of simultaneous studying of relatively large are surfaces;

– images extensionality;

– discrete or analogous registration of fast or slow processes of changing state of studying object;

– possibility of studying objects with diffusion-reflecting surfaces that is impossible for conventional interferometry;

– relative simplicity of holographic installations.

Disadvantages of the method:

– process of holograms recording and processing is quite difficult – low sensitivity of photographic materials requires exposition of several seconds at least;

– wet processing of photographic plates or servicing of equipment for thermoplastic recording and visual reading of interferograms requires special skills of operator;

– huge arrays of information are saved on photographic plates or on pictures made from holograms.

Up-to-date video- and computer devices allow to solve problems of holographic interferograms obtaining, storage, reading and processing.

Practical application of holographic methods of non-destructive inspection requires fulfilling following conditions:

– it is necessary to guarantee mechanical stability of an inspected object during all period of hologram exposure with high precision (the order of portions of light wave-length). Therefore, holographic installations have to be equipped with reliable vibro-protective system (weighty basement, dampings etc);

– it is more efficient to use lasers with high power to reduce exposure duration;

– registering mediums, used for holograms recording, have to possess high spatial resolution (with order 3000…4000 lines per 1 mm). Mostly halogenide-silver light-sensitive emulsions are used for holograms recording. The technology of getting information by means of holographic interferograms is very sensitive to even finest emulsion shrinkage which leads to distortion of recorded interferogram image and getting wrong results at its analysis. Therefore, photographic plates produced at industrial conditions can possess not fully removed residual stress inside emulsion layer that can distort final interference image. Plates of each batch are placed on 3…5 days to chamber with elevated humidity (85…90%) and room temperature without breach of packaging to remove possible residual stress. Then plates are moved to normal humidity medium up to removing of excess moisture from the package.

Microstructure of inspected object surface shouldn't be changed during hologram recording. Allowable changing of superficial micro-relief is doles of micrometer.

There are several options of the method of holographic interferometry realization, for example, interferometry in real time, the method of two expositions or temporary interval etc.

Interferometry in real time

After exposure and photographic processing a hologram is installed to the place of taking images, light with laser beam and observe an object through it after object loading. Hologram has to be placed exactly to the position it occupied during exposure. Interference picture in this case appears due to interference of two fonts of light waves: reflected from an object at moment of observation and from object beam recovered from the hologram. Interference strips are geometrical place of points of equal translations got by an object.

Holographic interferometry allows in real time to observe and register processes occurring in deformable body in time. However, some conditions have to be strongly kept. First of all, to organize visualization of interference image with consequent object change studying, the position on an object and its lightening at observation through processed hologram have to be the same like at original hologram recording. It means that both object and optical details of holographic installations have to stay in frozen state during time between exposure and observation or can be returned to original state with high precision. It is necessary to adjust interference structure created by object and reference beams during observation with the structure, which were recorded on hologram, with precision from doles of spacing between interference strips. Secondly, emulsion shrinkage, which occurs during photographic plate processing, causes unavoidable distortions of recovered wave fronts and correspondent distortion of interference image. Moreover, emulsion shrinkage continues up to photographic plate final drying that makes hologram installation by means of reference laser beam to be quite difficult.

Double-exposition interferometry

The method of holographic interferometry cab be also realized by another method. Holograms of an object at original and deformed state are recorded on the same photographic plate consequently (Fig. 9.2). Deformation of inspected object can be caused by different reasons, for example, by mechanical or heat influence. The same reference beam is used for both expositions. Distortions stipulated by emulsion shrinkage are the same for both restores waves and, therefore, don't influence disposition of strips created at their interference.

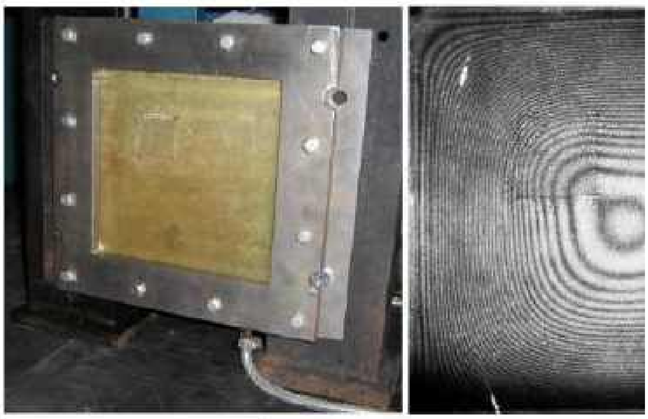


Fig. 9.2. Defects inspection of 8-layers glass plastic composite

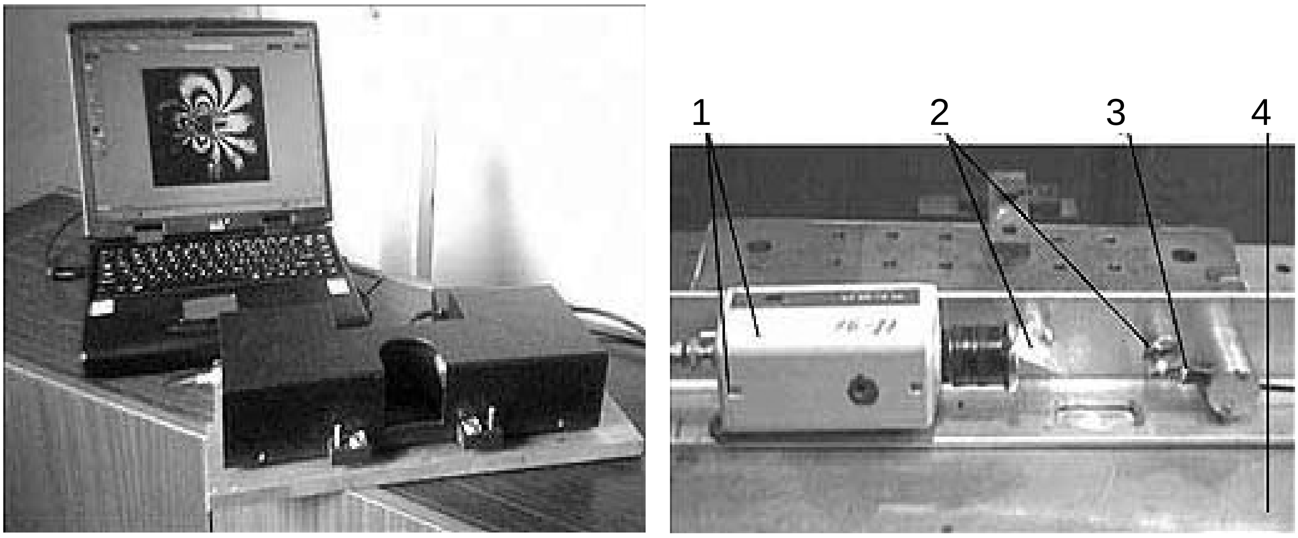
Electronic speckle-interferometry

Electronic speckle-interferometry is similar to holographic one. In both methods laser is used as a source of coherent emission. Methods have similar optical schemes and practically the same results of measuring like interferograms. Difference is in following: holographic interferometry records full information about body geometry, but speckle-interferometry uses electronic picture of especially fine, "grain"-like structure of light reflected by diffusion object to laser lightening – so called speckles (from English spark – flash of light and sparkle, i.e. to glister). Operator can see sparkles at zone lighten by laser. As detector photographic plate serves, video-camera records speckle as grain-like structure on the image. For holography speckle is interference, which worsen image. But for speckle-interferometry it is carrier of information because speckle-structure depends on surface shape and reflects quite good surface changing. Recording and comparison of two speckle-structures conducted by PC in digital mode allow to reveal changing in position or geometry of a body as system of lines like in holography, i.e. interferograms of the same sensitivity.

Decreasing of informability of speckle-interferogram comparing with holographic one due to replacement of volumetric image to flat one in negligible in current case. But from the point of methodology view generally non-uniform process of holographic interferometry is replaced by unified, technologically adjusted cycle with more wide capabilities for automatization.

Main feature of electronic speckle-interferometry is possibility to record of unlimited quantity of expositions and them combine them. Each combination will show shifting of an object between expositions. It is possible to compare frames not only of static state but also ones done in process of object movement. It is necessary only select duration of exposition and duration between expositions. Consequence expositions combinations will show correspondent object movement with sub-micrometer precision.

System of new generation (ЛИМОН-ТВ) for determination of stress in elastic bodies and structures was created based on electronic speckle-interferometry. This system includes ideas and methods of holographic interferometry developed earlier for residual stress analysis and advantages of up-to-date computer devices. Besides of stress analysis the system allows to solve such problems as determination of loads values and places of their application to elastic body, stress determination in thin films and joints, relationships between stress and mechanical properties, analysis of distributed and local non-uniformities of internal body structure, micro-cracks and inner delamination analysis, separation of coatings and deformation reasons of their appearing etc. Measuring can be conducted practically in real-time mode. Portable low-dimensional measuring system includes interferometry block of and computer block. Interferometry block consists of supporting-adjusting structure and case with built-in semi-conductive laser with wave-length 640 nm, video-recording camera with high sensitivity (0.1 lux) and resolution 600 television lines and other elements of optical scheme: directing mirrors, collimator, semi-transparent division mirror and diffusion-dissipating plate, which creates reference and objective light beams. Computer block in portable option consists of laptop with video-input to connect ordinary video camera. If video-input is absent outer device of Cap View type can be used as analogous-digital transformer. This device is connected to PC through USB port. Fig. 9.3 shows general view of computer interferometer ЛИМОН-ТВ and one of the option of optical scheme composition.



a b

Fig. 9.3. Computer interferometer ЛИМОН-ТВ: a – general view; b – optical scheme: 1 – video camera; 2 – system of rays division consisting of two semi-transparent mirrors and mat glass; 3 – semi-conductive laser; 4 – inspected object

Residual stress determination

The essence of the method for residual stress determination by means of sounding pit in combination with holographic interferometry is in following. During first exposition hologram of future pit on object surface at initial state is recorded. Then distortion of body surface is initiated (for example, small pit is drilled or etched) that generates residual stress because removing of a small volume of material leads to local elastic translations proportional to residual stress. Then hologram of distorted body surface is recorded. Due to overlapping of two holograms and their simultaneous restoration one can observe elastic displacements near pit as interferogram image. It is very visual and simple for decoding: in case of normal component of displacement registering (perpendicular to original body surface) strips of interferogram are lines of levels, i.e. lines of equal displacements, which differ by height on half of wave-length of laser emission $\lambda/2$ ~ 0.3 μm (Fig. 9.4). Symmetry axes of interference image coincide with directions of extremal (principal) tension and compression residual stress. Value of stress is proportional to number of interference strips. Moreover, strip division unit depends on elastic properties of material, pit diameter and depth and can be determined by diagrams (Fig. 9.5), composed by solution of 3D-problem of elasticity theory.

The quantity of necessary calculations for getting stress values is relatively small. And such calculations can be conducted by operator exactly after measurements and interference image observation. And in comparison with strain-gage testing where measurements are conducted for separate points the current method registers level lines of displacements near sounding pit over entire body surface that allows to determine visually directions of principal stress and make high quality conclusions about stress properties before their numerical values calculation.

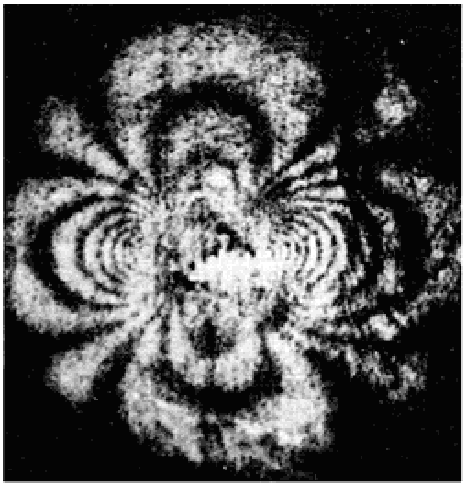


Fig. 9.4. Interferometric level lines of elastic displacements of body surface with residual stress at the neighborhood of scanning pit

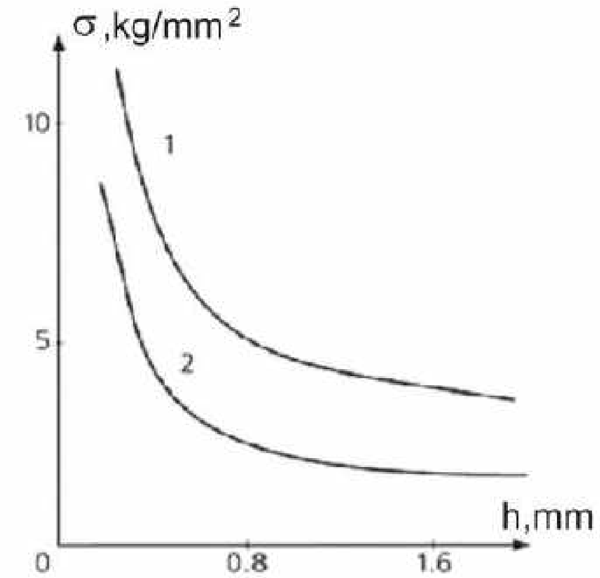


Fig. 9.5. Diagram of band value (stress σ as function of scanning pit depth h): *1* – at measuring by black band only; *2* – at measuring by both black and white bands

Portable holographic systems are used for of residual stress determination. Such systems measure different types of residual stress and are based on laser-interferometric method of stress determination (ЛИМОН). The systems were used for expert estimation of spacecraft self-failure reasons during long storage.

Checking-up problems

1. What is the essence of holographic method of quality inspection?
2. What are advantages of holographic method?
3. What are main conditions one has to keep at holographic methods of measuring conduction?
4. What variants of the holographic interferometry method do you know?
5. What is distinctive feature of interferometry in real time and double exposition interferometry?

10. X-RAY DEFECTOSCOPY AND RADIOGRAPHY

Last fifty years X-ray spectroscopy passed the way from getting images up to up-to-date multi-focus nanometer tubes. First projective X-ray microscope has appeared at the beginning of fifties of the last century.

X-rays were discovered in 1895 by German physician Vilhelm Conrad Röntgen. But practical application of these rays for small objects inspection was restricted because it was quite difficult to get small fucus spot and high resolution simultaneously. At the middle of last century engineers created beams of X-rays passed form the point with micrometer dimension but this technology was very complicated and used equipment was very expensive.

At the end of 1970-th “mini-focus” system of X-ray spectroscopy with resolution 30 msec was developed in British Harwell Institute. But this equipment stayed to be very complicated and expensive.

First commercial successful micro-focus X-ray tube with focus spot near 5 µm was developed and patented in 1982 by German engineer Alfred Reingold, who founded FEINFOCUS company. The invention was selected as a standard for X-ray inspection systems. And many manufacturers have started to suggest inspection systems based on FEINFOCUS technology.

Requirements to inspecting systems grows steadily. The dimension of focus spot has to be less than 1 µm. Nowadays nano-focus X-ray tubes are developed.

X-ray defectoscopy is based on X-ray absorption, which depends on medium density and atomic number of elements of inspected material. Fig. 10.1 shows scheme of X-ray inspection method. Presence of such defects like cracks, cavities or inclusions of other materials leads to beams weakening in different degree. It is possible to determine presence and location of non-uniformities in material by means of registering of intensity of passing rays distribution (Fig.10.2).

The method is used for revealing of porosities, inclusions of other materials, non-uniform increment of layers staking etc.

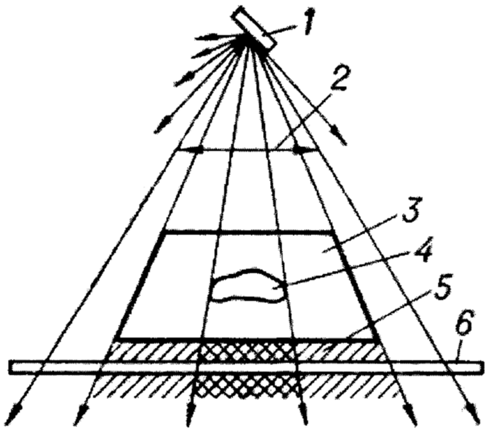


Fig. 10.1. Scheme of X-ray radiation: 1 – source of X-ray radiation; 2 – beam of X-rays; 3 – article; 4 – internal defect inside of article; 5 – X-ray image behind of article; 6 – recorder of X-ray radiation

Intensity of rays can be registered by several methods. Photographic methods record an article shot on film. Visual method is based on article observation on fluorescent screen. This method is more effective at application of electronic-optical transmitters. At xerographic method an article image is recorded on metal plates covered with substance to surface of which electrostatic charge is applied. Contrast images can be obtained on plates, which can be used many times. Ionization method is based on measuring of electromagnetic emission intension by its ionizing influence, for example, on gas. In this case indicator can be installed on enough distance from article that allows to inspect articles heated up to high temperature.

Sensitivity of X-ray defectoscopy is defined by longitudinal dimension of a defect in direction of radiation to article thickness at current cross-section and is equal to 1…10 % for different article materials.

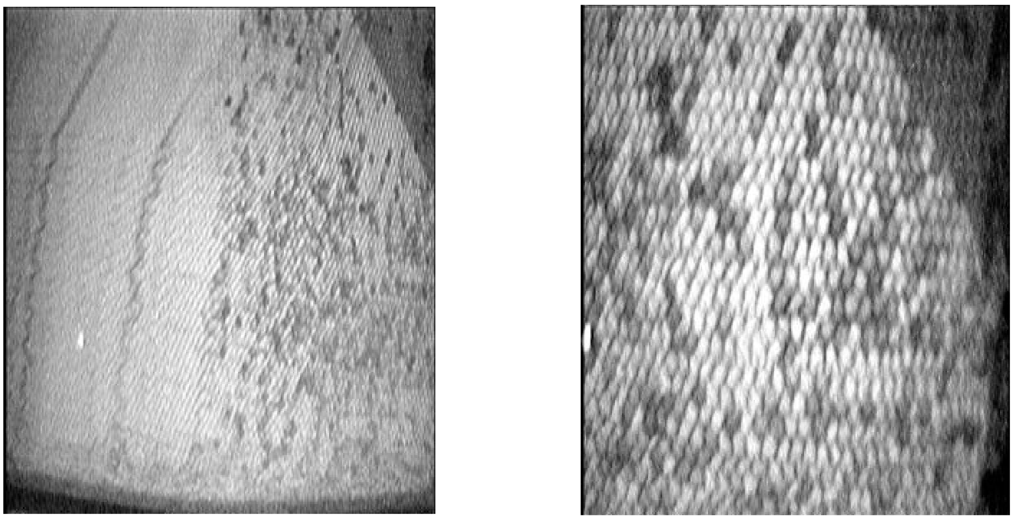


Fig.10.2. Picture of a unit containing moisture in honeycomb cell and its expanded view obtained by X-ray method

Equipment

Typical set of X-ray device includes:
- high-voltage generator;
- X-ray tube;
- system of X-ray tube cooling;
- digital control device;
- high-voltage cable.

To organize operation of X-ray devices special high-stabilized high-voltage generators have to be used (for example, generators of Spellman firm (Fig. 10.3)). Generators have high stability of current and voltage (long-term stability is not less than 0.1 %) and guarantee high rate of high voltage establishing.

Measuring can be conducted with high precision of parameters adjusting and their precise repeatability at inspection.

Nowadays one of the best metal-ceramic X-ray tubes are produced by Switzerland firm COMET (Fig. 10.4).

Fig. 10.3. Generator Spellman XRV160

Fig. 10.4. X-ray tube "MXR-350HP-11"

X-ray apparatuses are equipped with tubes with panoramic (360°) or straight directed (30…40°) diagram of X-ray emission in the range of voltage on tube anode from 100 to 450 kV. Metal-ceramic tubes COMET correspond to all requirements of safety and can be used for long-time operation.

Cooling of X-ray tube anode depends on tube type (unipolar or bipolar) and is conducted by means of water or oil cooling (Fig. 10.5).

In unipolar tubes (with voltage up to 225 kV) anode of a tube is cooled with distillated water or antifreezing liquid. In bipolar tubes (with voltage 320, 350, 420, 450 kV) anode is cooled with oil and oil in its turn is cooled with water and air. An example of such cooling system German one from Kluver firm can be considered. In this system liquid circulation between X-ray tube and heat exchanger with water-air cooling is pushed by pump.

Digital control panel for X-ray inspection apparatus is shown on Fig. 10.6.

Fig. 10.5. Cooling system OL-4503 for bipolar tube

Fig. 10.6. Digital control panel

X-ray television systems

X-ray television systems are used for getting images of inspecting object on the screen. X-ray image of an object is transformed by X-ray optical transmitter to visible picture, which in its turn is transformed to standard analogous or digital video signal.

Video signal is transmitted to analogous monitor to get image in real time and computer system of storing and perfection of X-ray images «Видео- Рен».

Fig. 10.7 shows universal X-ray television complex “Артикон 305”. The complex adopts very easily for problems of fully automized inspection and articles separation. Maximum mass of inspected object is 100 kg, height up to 500 mm, cross-section dimension up to 350 mm.

Software for digital processing and archiving of X-ray images allows to conduct automatic defects searching, measure their dimensions by their images and density profile, calibrate them by optical density.

Radiography is the method of getting visible images of internal structure of inspected object emitted by ionizing radiation.

Radiation methods of defects revealing are based on weakening of ionizing radiation by material of inspected object and use approaches of registration of radiation intensity behind of inspected object. Mostly X-ray films are used as registers of radiation in radiographic method. Internal defects location, shape, dimensions are defined by photographic image of shadow projection (X-ray shot)

Fig. 10.7. Universal X-ray-television complex “Артикон 305”

at inspection of objects.

Depending on used radiation X-ray spectrography, gammagraphy, betatronic, microtronic, neutronic radiography can be distinguished.

X-ray spectrography is generally used in industrial and rarely in field conditions, when strong requirements to article quality have to be fulfilled. Gammagraphy is recommended for inspection of thick articles and also butts at places with poor access, filed conditions and conditions of assembling. Betatronic and microtronic radiography is effective at inspection of articles with large thickness in industrial conditions.

Neutronic radiography is used for inspection of heavy metals, hydrogen containing materials and radioactive articles.

Digital radiography is the method of inspection based on ability of some luminophores to create hidden image in crystal grains of luminophore deposited on plate. Electrons appeared in luminophore due to radiation with X-ray or gamma-radiation are caught by energy levels and stay on them for a long time. From this state they can be left by laser beam. Reading of information recorded on fluorescent plate is possible by means of computer devices. Thus, this type of recording is called computer or digital radiography.

Digital radiography is used for getting images on special fluorescent recording plate of multiple use. Plates have typical for X-ray film dimensions 6x24, 6x48, 10x24, 10x48, 18x24, 24x30, 30x40 and 35x43 cm and can be exposed like photographic film in cassettes or flexible envelopes. To record image on plate special layer with photographic stimulating memory, i.e. special chemical compounds. Mostly compounds of BaFBrxI1-x:Eu2+ are used.

Complex of digital radiography «Градиент» with fluorescent recording plates (Fig. 10.8) possesses flexibility, reliability, high resolution and sensitivity, large dynamic range and simplicity of operation.

Complex of digital radiography «Градиент» with scanner Duerr and recording plates is developed especially for non-destructive inspection. Therefore, it is suitable for application with both X-ray and isotope sources.

Complexes allow to solve wide spectrum of problems of non-destructive inspection in such branches of industry as electrical energy, aerospace, oil and gas, automobile and others.

Electrons inside «fluorescent» crystals are excited and pass to quazi-stable state under influence of X-ray or gamma-radiation. Special reading device scans exposed plate by laser beam. During this process electrons are left from the trap that is accompanied by emission of visible light, wave-length of which differs from wave-length of scanning laser radiation. This light is gathered by photo-receiver and is converted to digital signal, transformed to digital image.

Cassette or flexible envelope with recording plate exposes like photographic film, i.e. is disposed behind inspected object. Plate is flexible and can be exposed without cassette of flexible envelope if necessary. Uploading and extraction of a plate from cassette or flexible envelope is conducted at room light without requirement of dark zone. Since sensitivity of plate is significantly more than film has then duration of plate exposition is 5…10 times less. After exposition plate is extracted from cassette or flexible envelope and placed inside scanner of digital radiography.

Fig.10.8. Complex of digital radiography «Градиент»

Image in scanner is read. The duration of image reading is form 10 sec up to several minutes and depends on dimensions of plate used and selected spatial resolution. Image is outputted to monitor, stored and protocol of inspecting is created. By means of special software read image can be enhanced by special filters and searching of defects, determination of their linear dimensions, generation of different conclusions etc can be done. After image reading information is removed from the plate and it is ready for new recording.

X-ray film viewers are used for decoding of radiographic shots.

Fig. 10.9 shows X-ray film viewer H 85/220 (Russia).

X-ray film viewer is lighting device with uniformly lighting screen and variable screen brightness.

The brightness is ensured by three halogen lamps of variable voltage. Brightness is regulated by voltage regulation. To protect radiographical shots from heat radiation special infrared filter is used.

Fig. 10.9. X-ray film viewer H 85/220

Detectors of X-ray and radiography inspection

Photographic sensitive film, photographic paper or semi-conductive plate can serve as detectors of radiographic inspection. Mostly X-ray film is used. In radiography engineers use property of X-ray film to become black after correspondent photographic processing under ionizing radiation influence.

Film is thin substrate of nitrocellulose or acetatcellulose on which layer of photographic emulsion is applied. Emulsion consists of suspension of microscopic crystals of bromine silver in gelatin (gelatin layer with the thickness of 0.001 mm protects emulsion layer).

Distinguishability of defects becomes more is colored radiography is used. I.e. lightening of inspected object with image registration on colored X-ray film. As a result, one can get images with colored contrasts, which are defined by material properties changing, sharp thickness variation.

Besides of X-ray film special semi-conductive transformers are used for recording of lightening results. Their influence is based on property of some materials to change conductivity under X-ray influence. Shadow X-ray image of lightening object is transformed by semi-conductive plate into 2D-relief of conduction by means of electric X-ray graphic apparatus. The transformer of image in this electric X-ray graphic apparatus is xerographic X-ray plate, which reacts to X-ray radiation passed through an object. The apparatus changes parameters of electric field in such way that residual charge is proportional to radiation intensity changing. Electrostatic image is transformed from photographic plate to paper by means of colored pigment-substances.

Checking-up problems

1. In what case X-ray spectroscopy and radiography analysis are used? How to conduct quality inspection by these methods?
2. What defects can be revealed by X-ray spectroscopy and radiography methods?
3. What sources of penetrative radiation are used in these methods?
4. What equipment is used for defectoscopy of composites by X-ray spectroscopy and radiography methods?

11. THERMAL METHOD OF NON-DESTRUCTIVE INSPECTION OF COMPOSITES AND INFRARED THERMOGRAPHY

Thermal methods of non-destructive inspection appeared at the beginning of 60-th of last century and are developed nowadays quite intensively.

Heat energy distributing inside inspected object is used in thermal methods of non-destructive inspection. Temperature distribution over inspected object surface is the main parameter in thermal method of inspection. Because it contains information about distinctions of heat exchange, operational regime of an object, its internal structure and presence of hidden internal defects. Local non-uniformities of thermal field on inspected object surface carry information about defects. Methods of heat inspection are based on interaction of an object thermal field with thermodynamically sensitive elements (thermocouple, photographic receiver, liquid crystal indicator etc), transformation of filed parameters (intensity, thermal gradient, contrast, radiancy etc) to electric signal and its sending to registering device.

Active method of heat inspection is used if inspected object doesn't subjected to enough thermal influence (for example, articles made of composites), or if temperature of an object doesn't change during operation. Active methof of thermal inspection assumes that object is heated with special outer energy sources to create heat flows during inspection. Active method is mainly used for non-destructive method of materials and articles quality inspection.

There are different methods of active thermal inspection of articles. Local short-time article heating with consequent temperature registration from the same surface (at single-side access) can be realized. Or temperature can be measured from opposite surface at double side inspection. Therefore, entire surface of an article is studies, moreover measured temperature of defect zones can differ significantly from the temperature of defectless zones. Another option means that scanning system is used. This system consists of source of heating and registering device (for example, radiometer) rigidly clamed with respect to each other. The system moves with constant speed over inspected article surface. For heat inspection of structural elements of aerospace objects one can use special radiometers ИИ- 30А and ИИ-40А, which are main parts of complicated defectoscopic complexes. Minimal dimensions of receiving optical block ИИ-30А allow to conduct inspection at articles and units zones with restricted access. Similar registration can be conducted by special apparatus "Термопрофиль." At simultaneous heating of entire article surface consequent registration of temperature distribution can be done by means of television station.

The essence of active heat inspection is in analysis of temperature response on given outer heat influence.

Depending on character of received information following types of inspection methods can be distinguished:

– heat defectoscopy, i.e. determination of defects presence and its location inside of inspected object;

– heat defectometry, i.e. methods and means of quantitative estimation of defects location depth and defects dimensions;

– heat tomography, i.e. the method of visualization of inner cross-sections of an object by means of heat effects, which allows to conduct entire analysis of inner structure of an object. It can be realized by impulse radiation of an object with flat uniform beam of radiation with consequent registration of “heat fingerprints” of defects or non-uniformities of heat-physical parameters of inspected medium on opposite side of an article by means of quick-registering thermal-vision system.

First two methods are quite deeply developed and used widely in the practice of heat inspection. Heat tomography is under development yet.

In aerospace industry active heat inspection is used for revealing of structural defects in composites, ready panels, adhesive joints, protective coatings etc.

Passive method of heat inspection doesn't require outer source of heat influence, heat field occurs inside of inspected object during its manufacturing or operation. At passive method both constantly influencing natural heat object loading (for example, operating engine, contact electrical joints under loading etc) or transition heat processes (for example, inspection of aviation honey-combs) can be used.

Thermal vision technical diagnostics by means of passive method is widely used in energetics, industry. Main advantage of the method is inspection of an objects without interruption of object ordinary operation or without special influence on it. Obviously, that successful application of heat method depends on development of measuring means, especially thermal vision devices. The portion of heat inspection problems, which can be solved by means of thermal vision systems, is very huge, therefore, the term "thermal vision inspection" is used. For example, industrial thermal vision devise Optris PI (Fig. 11.1) can be considered.


Fig. 11.1. Industrial thermal vision system Optris PI (manufacturer Optris GmbH, Germany)

It possesses following technical characteristics:

– temperature range – 20…900 °C;
– dimensions 45x45x62 mm;
– mass – 250 g;
– high sensitivity: NETD 0.08 K;
– sweeping frequency – 100 Hz;
– changable objectives: standard, wide angle lens and long focus;
– USB interface, USB power supply;
– cable with length 1.0, 5.0 or 20 m;
– analogous input and output, trigger.

Heat non-destructive testing can be conducted by following methods.

Vibro-thermal vision method is especially prospective for analysis of articles, which operate in vibrational conditions. Thermal fields appear in materials with defects under vibration influence. This phenomenon is stipulated by oscillation energy dissipation on defects and its conversion to heat. Zones of local object heating appear at zones of homogeneity violation. Defects like delamination, discontinuities etc can be sharply revealed on thermograms of vibrating plates.

Eddy-current heat method is based on radio-impulse exciting of metal objects by the field of inductor, receiving of heat response by near surface transformer during and after of heat influence, and analysis of amplitude-temporary information. Heat process is defined by heat-physical and electro-magnetic parameters of an object simultaneously. That allows to study object by heat and eddy-current heat methods during the same experiment. In partial case, coefficient of temperature conductivity is very sensitive to chemical composition and structure of materials (grain size, phase composition). By means of eddy-current heat method heat thickness measuring of ferromagnetic and thin-walled articles, articles with rough surface etc can be conducted.

Heat graphical non-destructive testing of composites is effective for inspection of thin-walled shells made of polymeric composites, strength of which depends significantly on defects like delamination, faulty of adhesive joints etc. This method includes heating (thermal loading) of an article and simultaneous registration of thermograms and holographic interferograms of heated surface. Defects can be found by presence of anomalous interference strips and the length of a defect and depth of disposition can be found by analysis of thermograms of inspected zone at heating by halogen lamp.

Heat inspection can be contact or contactless.

The method of infrared defectoscopy can be applied for contactless thermal inspection. All composites used in engineering can be divided on two groups: those can pass radiation flux and those can't pass radiation flux. Plastics, glass plastics, organic plastics relate to material which pass infrared radiation. Carbon plastic, boron plastic, metal material belong to group which doesn't pass infrared radiation. Transparency of materials for infrared radiation depends on filler and resin type, type of composite structure (regularity of filler laying-up, weaving method, fiber diameter etc), on refraction index of filler and resin material, adhesion of resin to filler etc.

Depending on degree of radiation flux passing through plastics and polymeric composites they can be divided on groups (Fig. 11.2):

– with directed passing (1) (different organic glasses, polystyrene, viniplast, cured polyester and epoxy resins, polyethylene etc). For such materials following condition is valid: $\alpha=\alpha_1$;

– with directed-dissipated passing (2);

– with dissipated (diffusion) passing (3) (glass plastics, glass-organic plastics, asboplastics, foam plastics etc);

– with mixed passing;

– non-transparent (doesn't pass infrared radiation).

Revealing of defects in composites with infrared method is based on registration of radiation reflected or passed through inspected medium.

Process of defects inspection is the following. The flux of infrared radiation is created by emitter and directed to an article. The spectrum of emitted signal depends on infrared source type, optical properties of inspected material, article thickness and some other factors. But, considering, that many types of plastics have transparency bands on different wave-length it is more efficient to use sources of radiation with wide spectrum. One more important requirement to infrared sources is constant intensity of radiation.

Radiation passed through article has got information about properties and structure of a material. This signal is received by transducer, in which radiation energy is converted to electrical signal, amplified up to power, necessary for operation of photographic modulation lamp. Photographic modulation lamp transforms electrical signal to light one, which then is projected to photographic material (film, plate, paper). The brightness of light signal is proportional to intensity of radiation passed through an article.

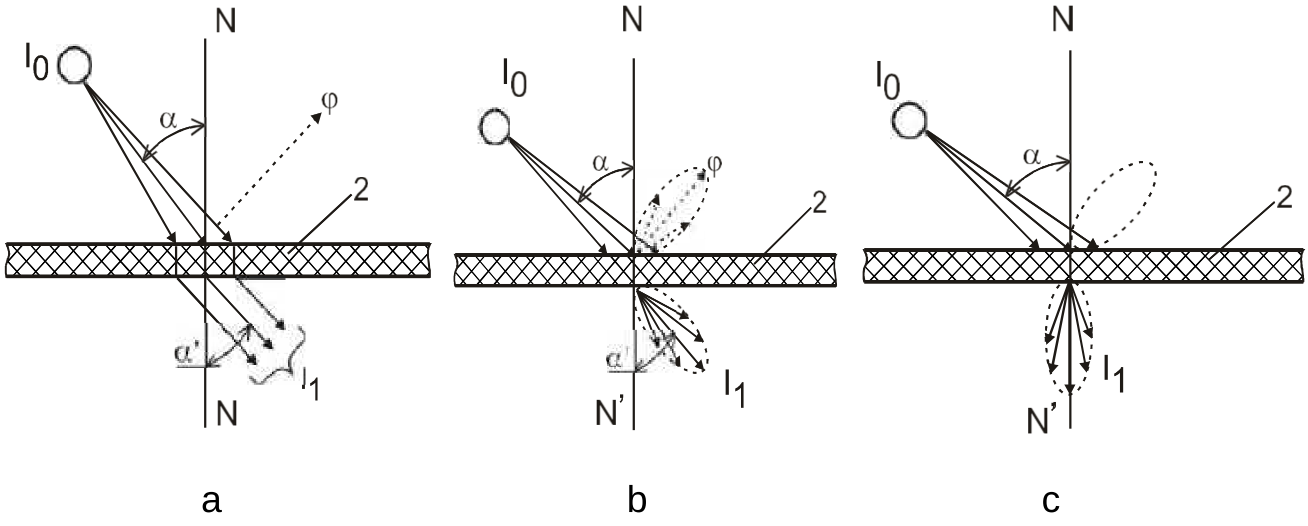


Fig. 11.2. Division of material on groups depending on degree of radiation flux passing

Scheme of device for the method of infrared defectoscopy is shown on Fig. 11.3.

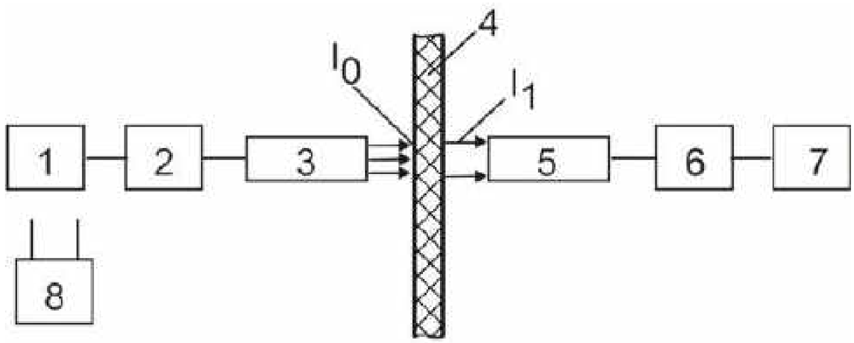


Fig. 11.3. Scheme of device for the method of infrared defectoscopy of composites: 1 – sound generator; 2 – amplifier; 3 – source of infrared emission; 4 – inspected specimen made of composite; 5 – receiver of infrared emission; 6 – amplifier; 7 – registering device; 8 – power supply block

Emission part of installation is developed for infrared radiation in form of rectangular impulses with frequency 30 kHz. It consists of sound generator 1, current amplifier 2 and source of infrared radiation 3. As the source of radiation injector laser is used. Laser transforms electrical impulses to infrared radiation. Receiving part of installation includes receiver 5 (photo-diode sensitive to infrared radiation), amplifier 6 and registering device 7. Oscillograph is used as registering device. Power supply block 8 feeds system with single-polar stabilized voltage of 12 V.

Possibility of revealing defects and inner material structure is based on strong dependence between optical density of inspected material and intensity of passed radiation energy. In process of radiation energy transferring changing of its value and spectrum composition occurs. The value of energy changes due to absorption and dissipation of radiation flux by inspected medium, through which the flux spreads.

Changing of spectrum composition of a flux is stipulated by following: separate components of a medium differently absorb and dissipate infrared radiation.

Using infrared method engineer can get photographic evidence which characterizes inner state of inspected article. Therefore, it is possible to determine parameters of radiation flux and then by their analysis one can estimate material quality both in process of manufacturing and in operation. The method is used for revealing of reinforcing material shifting, wrinkles appearing at operlapping, zones with elevated porosity, delamination, faulty of adhesion, inclusions of other substances etc (Figs 11.4, 11.5, 11.6).

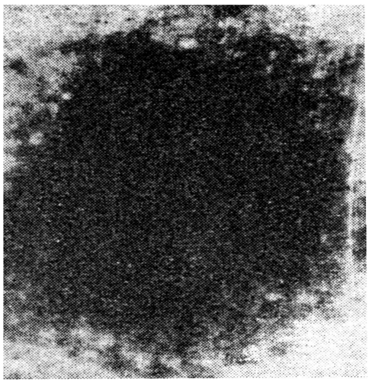


Fig. 11.4. Photo-defectogram of plate made of glass-fiber composite with inner cavity (dark zone), edges of cavity have elevated porosity

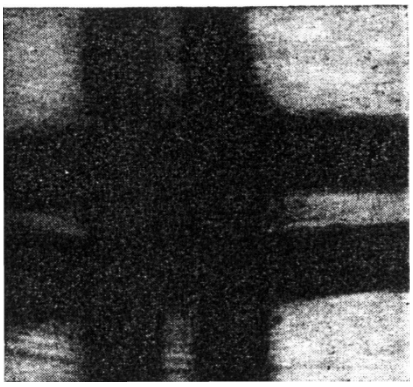


Fig.11.5. Photo-defectogram of plate made of glass-fiber composite with thickness 25 mm having artificial wrinkles created in two layers on the depth 12 mm

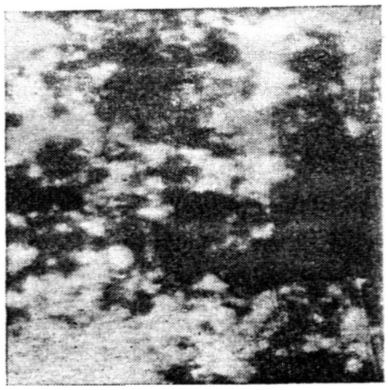


Fig.11.6. Photo-defectogram of plate made of glass-fiber composite with thickness 7 mm having elevated porosity

Besides of mentioned, special termal paints, thermal paper, termal luminophors, liquid crystal thermal indicators etc can be used for the methof of thermal inspection.

Advantages of the method:

– distant measuring;
– high rate of information analysis;
– high rate of testing;
– high resolution;
– high sensitivity чувствительность;
– possibility to inspect defect at single- and double side access to article;
– theoretically any materials can be tested;
– multiparametric character of testing;
– compatibility with standard systems of information processing;
– possibility of flow inspection and creation of automized systems for

inspection and manufacturing process control;

– possibility to get photographic evidence, which characterizes internal state of inspected article.

Checking-up problems

1. What is the essence of heat method of quality detection?
2. What are main advantages of infrared method.
3. What defects can be revealed by infrared method?
4. What equipment is used at detection by infrared method?

12. QUALITY CONTROL OF PROTECTIVE DIELECTRIC COATINGS

Generally, majority of aviation metal structures are covered with protective coatings to guarantee their corrosion and heat protection, increase their tightness and visual view. For this purpose, dielectric materials like varnishes, paints, enamels, ceramics, plastics, epoxy, polymeric and other materials are used. Moreover, articles made of aluminum all are subjected to anodizing before protective coating application.

Quality of such coatings has to be inspected by non-destructive methods. It is necessary to control their thickness and also defects or damages (cracks, delamination, bubbles etc).

Especially dangerous are through thickness violations of coating continuity through which corrosion-active medium can interact with metal surface.

Measuring thickness of protective dielectric coatings

To determine thickness of protective dielectric coating the method of eddy-current is used. It ensures local and contactless measuring at single-side access to a structure with high precision.

The method is based on dependence of article material parameters (for example, resistance) on spacing up to conductive surface.

But precision of measuring depends on surface curvature, distance up to article edge, presence of holes and protruding parts.

Up-to-date eddy-current thickness measuring devices are produced by following companies: Elcometer (Grate Britain), Institut Dr. Foster и Fischer (Germany), «Константа» (Russia), «Кром» (Ukraine, Dnepr), «Леотест-Медіум» (Ukraine, Lviv).

Thickness measuring devices ВТА of company «Леотест-Медиум» are developed for measuring thickness of different range (Table 12.1). Devices ВТА can be used for measuring thickness of anode-oxide coatings on aluminum alloys.

Table 12.1

Parameters of thickness measuring devices

Thickness measuring device	Detectable range of protective coatings thickness, mm	Error of measurements, %
BTA-03	0…0.3	2.0
BTA-4	0…5.0	1.0
BTA-20	0…20	1.5
BTA-40	0…80	1.5

Fig. 12.1 shows multi-function electromagnetic thickness measuring device “Константа К5” for protective coatings of all types. Device allows to control geometrical parameters and electro-physical characteristics of articles and also quality of surface preparation. This device one can control galvanic, paint-varnish, plaque, powder, plastic, anode-oxide and other special coatings with thickness up to 120 mm on metal articles according to standard ISO 2808.

Fig. 12.1. Device for measuring thickness of protective coatings «Константа К5»

Company DeFelsko produces different thickness measuring devices for coatings.

Ultrasonic thickness measuring device for coatings PosiTector 200 (Fig.12.2) is used for measuring thickness of coatings on composites. By means of PosiTector 200 one can measure thickness of separate layers.

Thickness measuring device PosiTector 6000 is shown on Fig. 12.3. The operational principle of PosiTector 6000 is based on eddy-current method of protective coatings thickness measuring. The device can be used for measuring coatings on any metals.

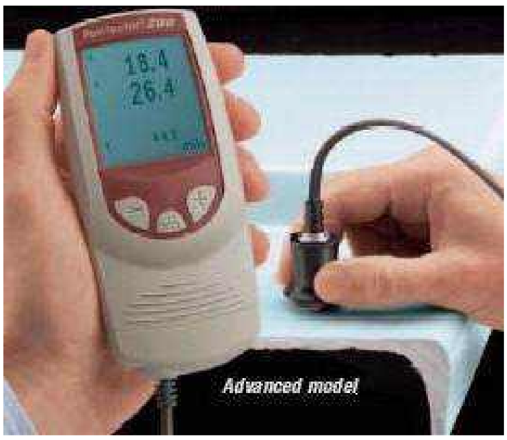


Fig. 12.2. Ultrasonic coatings thickness measuring device PosiTector 200

Fig. 12.3. Coatings thickness measuring device PosiTector 6000

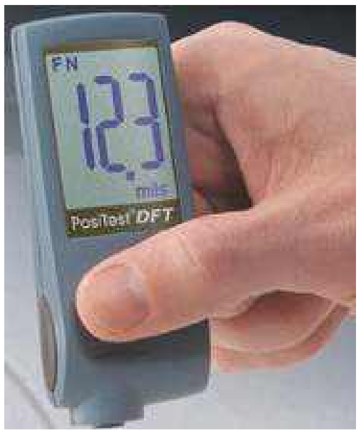


Fig. 12.4. Coatings thickness measuring device PosiTest DFT

Fig. 12.4 shows eddy-current thickness measuring device for coatings PosiTest DFT. The device is used for measuring thickness of coatings on all metals with high quality of inspection.

Small magnetic thickness measuring device PosiPen (Fig. 12.5) is developed for measuring coating thickness on steel. Due small dimensions and tiny measuring gage it allows to measure thickness in zones with restricted access and on small zones of an article.

Magnetic thickness measuring device for coatings Positest F/G (Fig. 12.6) is simple cheap device for measuring thickness of paints, enamels, galvanic coatings on steel.

Fig. 12.5. Magnetic thickness measuring device PosiPen

Fig. 12.6. Magnetic device for coatings thickness measuring Positest F/G

Defectoscopy of protective dielectric coatings

To control continuity violation in protective coatings with thickness up to 500 μm “wet” method is used. It means measuring resistance of contour “wet” electrode–metal basement of an article.

«Wet» electrode is a sponge impregnated with electrolyte. The sponge is attached to inspecting coating. Resistance reduces sharply at places of through thickness damages where electrolyte is penetrated. Such devices are produced by company Elektro-Physik (Germany). Device 204Pin Hole Detector is used for inspection of coatings with thickness up to 300 μm, device 269Pin Hole Detector – for coatings with thickness up to 500 μm.

This method can’t be used for defectoscopy of very thick coatings due to capillary effect which prevents filling of thin holes and damaged coatings with electrolyte.

To inspect continuity of thick coatings electric spart method is used. It is based on electric breakdown of air-filled gaps between probe and metal basement of inspected article.

Main manufacturers of electric spark defectoscopes Pro Test is company Elektro-Physik (Germany), «Корона-2М» – company «Интроскоп» (Moldova), «Пульсар 2J» (Ukraine, Lviv).

Defectoscope «Пульсар 2J» ensures inspection of through thickness defects with diameter not less than 0.3 mm in insulation coatings with thickness up to 9.5 mm. The rate of probe movement is up to 0.35 m/sec. Spacing between two defects which can be found not less than 15 mm. Light and sound indication of defects is possible.

Electric spark defectoscope «Корона-2» (Fig. 12.7) for inspection of continuity of dielectric coatings is used for coatings with thickness up to 10 mm.

Fig. 12.7. Electric spark defectoscope «Корона-2»

Adhesion measuring devices

Adhesion measuring device Positest AT-A (Fig. 12.8) with automatic loading measures adhesion of coatings to substrates. It can self-center (Fig. 12.9) and adjust necessary tearing rate. Adhesion measuring device Positest AT-A can also compensate non-axiality. Rough surface of coating cause non-uniform tearing force applied during testing and result of measuring can be incorrect. To get adhesion value with better repeatability and more reliable engineer has to guaranty that tearing force applied to rest was uniformly distributed over testing surface.

Self-centering mechanism with quick clamping and spherically supported head of rest ensures uniform distribution of tearing-out load over inspected surface preventing one-side tearing-out.

Fig. 12.8. Adhesion measuring device Positest AT-A

Fig. 12.9. Self-centering mechanism

Adhesion measuring device PosiTest AT (Fig. 12.10) measures adhesion of coatings to metal and other substrates. The device is equipped with indicator of tearing rate and maximum pressure at tearing and also have possibility for self-centering.

Fig. 12.10. Adhesion measuring device PosiTest AT

Inspection of coating impact strength

Device «Удар-Тестер» (Fig. 12.11) is used to inspect strength of protective coating at impact. Arrangement of the device corresponds to requirements of international standard ISO 6272. It is used in industrial laboratories at incoming control of coatings, during manufacturing and in field conditions at objects operation.

Fig. 12.11. Device «Удар-Тестер»

Checking-up problems

1. In what cases inspection of protective dielectric coatings is necessary?
2. What types of inspection for protective dielectric coatings do you know?
3. How measuring of thickness for protective dielectric coatings is conducted? What equipment is used for this inspection?
4. What are main methods of defectoscopy for protective dielectric coatings?

What equipment is used for each method?

5. What types of ultrasonic thickness measuring devices do you know?

6. What physical principle do impulse ultrasonic thickness measuring devices use? What precision of thickness measurement does this method guarantee?

7. In what case resonance ultrasonic thickness measuring devices are used?

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