SECTION 5
DIAGNOSTICS AND METCHODS OF RESEARCHES

APPLICATION OF ACTIVE THERMOGRAPHY FOR DEFECTOSCOPY OF TECHNOLOGICAL EQUIPMENT ON OBJECTS OF THE NUCLEAR POWER PLANTS

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The methodical and physical bases of the use of active thermography as a high-performance non-destructive method of control and defectoscopy of materials during thermovision monitoring of technological equipment at NPP objects are considered. The data of experimental research confirm the efficiency of the use of thermal and low-frequency electromagnetic activators in the thermographic defectoscopy. The features of the application of dynamic thermography and the influence of external activation sources on the thermal appearance of structural inhomogeneities and defects in materials are investigated. It is shown that the application of special methods of processing thermal images that take into account the amplitude-frequency and morphological features of thermoanomalies, allows to control the thermal display of energy-absorbing structures and defects, provide the possibility of their identification against the background of false thermoanomalies.

PACS: 65.90.+I

INTRODUCTION

One of the most important conditions that ensure the reliability and safety of existing NPPs is the use of non-destructive testing techniques for detecting defective zones during the operation of power units, accounting for aging of materials during the operation of equipment and pipelines of the NPP, improvement and optimization of control systems for mechanical properties and defects in materials equipment and pipelines. Taking into account the magnitude of these objects, this problem can be solved with the use of thermal monitoring – a high-performance non-destructive method of control based on infrared radiometry. The application of thermal imaging monitoring of technical equipment without their withdrawal from exploitation, the detection of defects in materials at an early stage of their development significantly increases the reliability and safety of the operation of nuclear power facilities.

1. METHODOLOGY AND PHYSICAL BASES

The technology of remote infrared radiometry based on the registration of the infrared radiation from the surface of the control objects and the subsequent analysis of their thermal images (thermal cards, thermograms) are the basis of the thermal imaging control and defectoscopy technique. The spatio-temporal distribution of temperature on the surface of physical objects reflects their structure, is an information field, by means of which hidden defects and defect-forming zones are detected, a classification of defects is carried out [1–3]. The presence of a defect in such a diagnosis is reflected by the magnitude of the abnormal change in the radiation temperature and the nature of its distribution on the background of a defect-free temperature level, formed by inhomogeneities of the radiation ability of the surface $\varepsilon(\lambda, T)$ of the object of control and the fluctuations of the radiation temperature of the noise components of the external obstacles. The necessary condition for the thermal display of a defective structure is the violation of the thermodynamic equilibrium of the object with the environment under the influence of external sources of thermal activation or the influence of natural or man-made perturbing factors. At the same time, on the surface of the control object there is an excessive temperature field that carries information about the structural features of the material. Real energy equipment is characterized by unsystematic thermal processes and a change in the time boundary conditions of heat exchange, which plays a decisive role. Temperature anomalies caused by heat exchange processes in the field of hidden defects and energy absorbing (defective) structures affect the formation of the thermal regime, which is reflected on the temperature field and the field of infrared radiation of the object of control. Information about the thermophysical state of an object with sufficient accuracy can be obtained by means of thermographic measurements using remote infrared radiometric methods. The application of the thermographic method of defectoscopy and diagnostics on the basis of the analysis of the temperature field dynamics allows to determine the structural irreversible changes and damage to the material of structures through fatigue or critical loads, the change of optimized parameters of the working equipment, to identify defects at an early stage of their development.

1.1. ACTIVATION OF DEFECTS STRUCTURES IN TERMOGRAPHY

In order to activate the thermal manifestation of defective structures/defects in materials, the external energy influence sufficient to transfer the sample into a thermodynamic state, which provides the necessary level of temperature contrast of thermal imaging of structural inhomogeneities, is used. Identity defects are manifested through the temperature response to the thermal effects that the subject of the study is exposed to. Due to the difference in the thermophysical properties of the main material and third-party inclusions (defects) during thermal activation, temperature fields are created that reflect the structure and condition of the object of the study. Informative parameters of the temperature field (amplitude, temperature gradient, spatial characteristics of the distribution of thermoanomalies) reflect the features of the internal structure of matter, in particular, the presence of structural inhomogeneities and defects. This allows us to detect irrelevance (cracks, porosity, extraneous inclusion) of materials, changes in their structure and physical and chemical properties. External energy effects may be thermal activation that provides direct heating/cooling of the sample, as well as acoustic or electromagnetic (induction) activations based on the use of the thermophysical effects of transforming the energy of waves into heat when interacting with the environment of the control object. In these cases, the defects themselves are sources of active thermoforming (generators of thermal energy), which finds its reflection on the thermal image of the object of control. An important advantage of the methods of thermographic control based on induction activation is the possibility of defectoscopy of metal structures containing welded compounds and many types of various defects that arose both during the manufacturing stage and the operation of the control object. Induction thermography allows to change the electromagnetic parameters in the local zones of ferromagnetic materials to control macro- and microstructural changes in physical and mechanical properties under the influence of various critical loads and disturbance factors (plastic deformation of structural materials, which leads to accumulation of micro- and macrostructural injuries, changes in the location of dislocations, occurrence of damages and macrodefects of fatigue, imperfect defects and crack-like external and internal defects).

1.2. FORMATION AND REGISTRATION OF INFORMATION FIELDS OF IR-RADIATION

In general, the temperature field of an object's surface is represented by the temperature function $T(x_1, x_2, x_3, \tau; \psi_1, \ldots, \psi_s)$, where x_1, x_2, x_3 – are spatial coordinates, τ – time, $\psi_1, \ldots, \psi_s$ – parameters of the thermophysical processes, materials and structures of the object of control, which influence the formation of the temperature field. Thermal imaging in the form of a set of thermograms ($\tilde{\bar{T}}$, n_1, n_2, k) is formed by temporal and spatial sampling of the temperature field of the control object. In the problems of active thermal control [4] the informative physical field is the field of the heat flux vector $Q(q_i,\tau)$, as well as the Fourier equation of the scalar temperature field $T(q_i,\tau)$:

$$Q = -\lambda \nabla T \quad , \tag{1}$$

where q_i – generalized coordinate; τ – is the time; λ – coefficient of thermal conductivity, W/(m·K). The process of propagation of heat in solids proceeds in space and in time, it is associated with the formation of stationary $T = f(x, y, z)$ and non-stationary temperature fields $T = f(x, y, z, \tau)$ [5, 6]. At the same time, the vectors of the gradients of temperature and heat flow form a picture of the spatial distribution and directions of the transition of thermal energy. The heat flux density $q = -\lambda \, dT/dn$ (where n – is normal to the isothermal surface) through the isothermal surface F separation is proportional to the gradient temperature $grad\, T = dT/dn$. The amount of heat transmitted, according to the Fourier law, is equal to

$$dQ = -\lambda dT/dndF \, d\tau = q \, dF \, d\tau. \tag{2}$$

Detection of thermal phenomena of defects in real conditions is carried out against the backdrop of fluctuations of the radiation barrier, temperature noise due to the fluctuation of the absorption coefficient and the influence of the heat transfer conditions by convection (determined by the values of the coefficient of convection) heat transfer and the coefficient of radiation (affects the value of temperature differences over the defect) [7, 8]. The value of the emission factor ε can vary within (0.3…0.98). On a homogeneous surface of the radiation, the fluctuation value ε is from 0.001 to 0.01 units, which o corresponds to the fluctuation of the recorded radiation temperature in the range of 0.05…0.3 K, respectively, with the background temperature T_f = 300 K. The spread ε on the surface of the inhomogeneous object can vary by 30…50% (with possible values $0 \le \varepsilon \le 1$). For this reason, the more heated polished metal surfaces ($\varepsilon \le 0.2$) will be visualized as more "cold" relative to those having a lowered temperature of rough (oxidized) areas or paint coatings with $\varepsilon \ge 0.8$. For values $\varepsilon \le 0.9$, it is necessary to take into account the obstacles caused by the irradiation of the object of control by more heated adjacent bodies (having higher values of T, ε).

2. CHOICE OF THE THERMAL ACTIVATION MODE

In order to solve the practical problems of thermographic defectoscopy, an orderly mode of thermal activation is used in many cases to provide the most accurate manifestation of thermoanomalies due to thermophysical inhomogeneities of the controlled medium, and the research object asymptotically passes to the equilibrium thermodynamic state. The mode of heating (or cooling) of the body by a constant heat flux (q_c = const) is quasi-stationary, and its temperature, starting at some point in time, varies according to the law of the straight line. Under the action of a constant heat flux after the end of a certain time segment ($\tau > \tau^*$), the temperature field on the surface of the body is described by the simplified function $T = T_o + b\,\tau$, where T_o is the initial body temperature; b is the heating rate, K/s [4, 9]. The monotonic mode (smooth heating or cooling of bodies in a wide range of temperature variations with a weakly variable velocity field inside the sample) is a generalization of a quasi-stationary thermal regime and is used, as a rule, in cases with varying thermophysical properties of substances: $\lambda = \lambda(t)$; $a = a(t)$; $c\rho = c\rho(t)$ and the heating rate (cooling) $b = b(x, \tau)$ [10, 11]. Particular attention deserves induction thermography, based on the activation of ferromagnetic materials by low-frequency electromagnetic fields. Irreversible processes of transformation of electromagnetic energy into heat on structural inhomogeneities and defects in magnetically ordered solids (losses on hysteresis, dynamic losses) reflect the state of the structure and continuity of the material, its physical properties. The small value of the energy of the activating effect leads to the rapid dissipation of the thermal energy, which time is commensurate with the time of the temperature manifestation on the surface. This reservation is especially justifiable for metals [11]. It should be borne in mind that when thermal imaging thermography the information field of infrared radiation is formed by the thermal fields of the object of research as a result of the direct transformation of electromagnetic energy into heat in defective structures, and the influence of defective structures on the redistribution of heat flows that are created by surface vortical currents.

3. PRACTICE OF APPLICATION OF DYNAMICS TERMOGRAPHY

The advantage of dynamic thermography in comparison with stationary methods is a higher level of thermal display of defects, which slightly affect the stationary temperature distribution during transients. In this case, the ability to predict and detect defects in materials and structures at an early stage of their development is provided. The method is based on the correlation analysis of the temperature field dynamics obtained with a certain time step. Areas of discrepancies in geometric parameters of consistently taken thermal images are identification signs of the output of an object from a normal state or the existence of a hidden defect. Significant temperature differences near defects in transient processes are limited by the time of their existence, which imposes certain requirements on the speed and temperature sensitivity of hardware thermographic control. As experience of carrying out experimental research shows, thermographic control on the basis of thermal monitoring monitoring ensures the possibility of defectoscopy of technological equipment and metal structures of NPPs: welded joints (the intensity of corrosion wear of welded joints and the presence of cracks in the parietal zone, non-porous, etc.), to control in local zones of ferromagnetic materials macro- and microstructural changes of physical-mechanical properties under the influence of different loads and disturbing factors. The experience of using our experimental samples of low-frequency electromagnetic activators during thermographic defectoscopy of products from ferromagnetic materials confirms the possibility of registration of parameters, thermal display of defective structures and their identification, depending on thermal and physical parameters of density and elasticity of materials. Earlier [12, 13], we have considered the physical and technical foundations of thermographic defectoscopy of ferromagnetic materials at low frequency (50 Hz) inductive and acoustic [14] activation, the basic schemes of electromagnetic activators are given, the technical characteristics of the experimental electrophysical equipment, some results of experimental studies by thermal imaging means of control of thermographic characteristics and characteristics thermal display of structural inhomogeneities and defects in materials that arise during the operation of the NPP equipment. In the analysis of thermal images of pipeline fragments of the NPP technical water supply system (Zaporizka NPP), it was discovered that even under protective anti-corrosive paint and varnish coatings, corrosion and erosion damage/defects and also the detachment and swelling of the coatings are particularly clearly manifested. The amplitude of the thermal display of such defects reaches 0.4…3 °C, (Fig. 1).

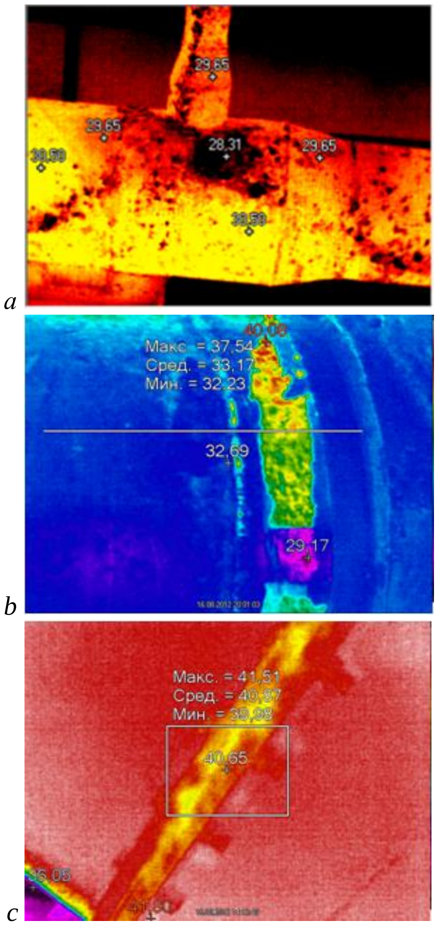
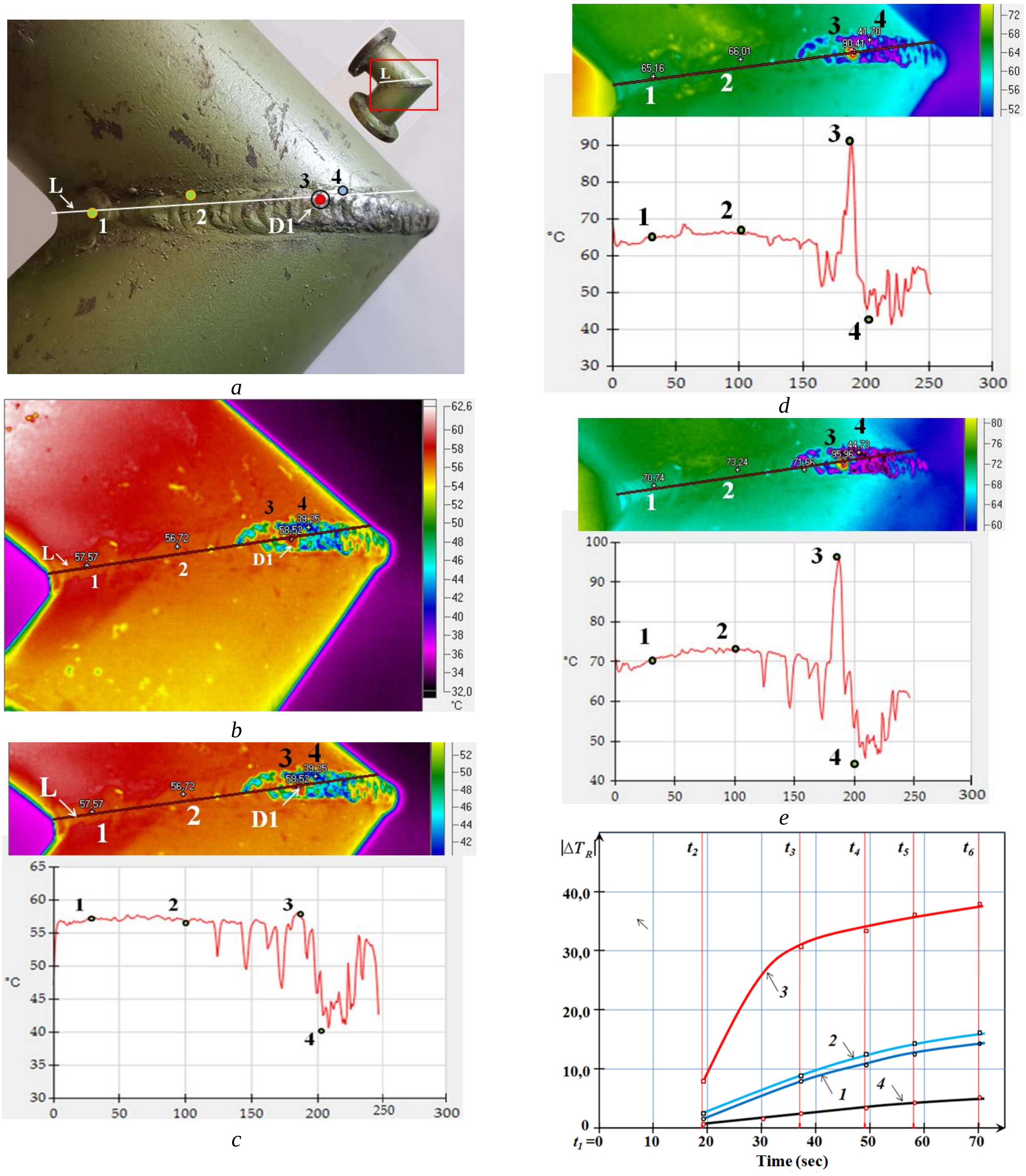


Fig. 1. Thermal image of external pipelines of spray pools (a) and fragments of combination (b, c) of underground pipelines VF10 and VF20 from underground wells by means of thermal imaging control. The temperature of technical water in the pipelines (b, c) is 33 and 42 °C, respectively

At the same time, complexity arises when identifying defects (fistulas, cracks, third-party inclusions), located directly on the weld. Because of the heterogeneity of the surface of the radiation and the thickness of the weld, its thermal display on the thermal image (map of the radiation temperature distribution) of the control object is displayed in the form of a homogeneous amplitude and morphological features of the structure of the image of the thermoanomal zone located along the weld.

3.1. ANALYSIS OF THE RESULTS OF EXPERIMENTAL STUDIES

In order to increase the effectiveness of detecting defects in the welds of pipe joints in real production conditions, we have considered the possibility of using a dynamic thermal imaging thermography, in which activation is carried out by blowing the object of control with hot air (thermal activation). The effectiveness of detecting a defect such as “through fusion on a weld” with this activation method is demonstrated on the structural element of the pipeline (Fig. 2). Under the condition of the quasi-stationary thermal state of the sample (before the start of thermal activation, $t_1=0$), the thermoanomaly ΔT_R defect/fistula D1 (see Fig. 2,a, point 3 on the weld) on the thermal image of the weld (see Fig. 2,b,c) is practically not identified due to the presence on the surface of a large number of thermoanomal zones with amplitudes of thermoanomalies with respect to the background temperature from 0.1…0.2 to 2…15 °C due to the fluctuation of the radiation coefficient ε.



a

b

c

d

e

f

Fig. 2. Thermal display of a defect (fistula) in a welded joint of a pipe connection at the thermal activation of the sample (material – steel St.30, diameter of the pipe – 70 mm, wall thickness – 3 mm, through fistula, diameter 1 mm); a – a picture of a sample: 1, 2 – a control point on a weld joint with an unbreakable layer of paint and varnish coating, 3 – the control point on the hidden defect D1, 4 – a control point on the weld area without paint and varnish coating; b – thermal image of the sample in the zone of activation; c, d, e – thermal image and thermogram of the sample fragment through the control of the weld seam at the beginning of activation ($t_1 = 0$), for 37 s ($t_3 = 37$ s) and for 70 s ($t_4 = 70$ s) respectively; f – dynamics of change in the radiation temperature at the control points 1, 2, 3, and 4 in the process of thermal activation of the sample

On the photographic and thermal images of the sample (see Fig. 2,a,b), on the line L along the weld, the points of control allocated to the zones with the undamaged layer of paint and varnish coating (points 1, 2, the amplitude of the thermoanomalies less than + 0.1 °C, the defect D1 (point 3, +1.5 °C) and weld seam zone (point 4) without paint coating – 14 °C. The temperature jump, which is due to the difference in radiation coefficients at the edge of the paint coating and the pure metal, varies from 10 °C (the temperature of the sample is + 57 °C) to 17 °C. In Fig. 2 (at control points 1, 2, 3, and 4,d,e shows the thermal imaging of the activation zone of the sample and for 37 s ($t_3 = 37$ s) and for 70 s ($t_6 = 70$ s), and in Fig 2,f – dynamics of change of radiation temperature $\Delta \boldsymbol{T}_{\boldsymbol{R}}$ – *1*, $\Delta \boldsymbol{T}_{\boldsymbol{R}}$ – *2*, $\Delta \boldsymbol{T}_{\boldsymbol{R}}$ – *3*, $\Delta \boldsymbol{T}_{\boldsymbol{R}}$ – *4* respectively) in the process of thermal activation. It is evident that in the process of thermal activation, the greatest change in the radiation temperature is observed on the defect D1: at 37 s – 30 °C, at 70 s – 37°C. At selected control points 1, 2, 4 the dynamics of temperature growth is much less (1 – 7, 14 °C; 2 – 8, 16 °C; 4 – 3.5 °C). The analysis of the thermal characteristics of the type of defect under consideration during thermal activation of the sample shows that the identification signs of such defects against the background of false thermoanomalies are abnormally high values of the amplitude (up to 37 °C) and the temperature gradient ∇T_R (over 30 °C/mm) within the thermoanomaly, as well as nonlinear the nature of the change in the amplitude of the thermoanomal in the heating process. The smallest change in the amplitude of the thermoanomalies is observed in the sections of the weld with a broken paint and coating coating on which pure metal is observed ($\varepsilon \leq 0.5$).

Investigation of the features of the thermomanifestation of a defect-free weld (Fig. 3) protected by multilayer paint and varnish coating was carried out by activating the specimen with hot air (thermal activation) and low-frequency (50 Hz) electromagnetic field (induction activation). In Fig. 4 shows the thermal imaging and thermogram *LT* of the distribution of the radiation temperature along the line *L* of the weld at different stages of the experiment: a_o, *a* – thermal image and thermogram L_T along the line *L* in the beginning and for 290 s of thermal activation of the sample; c_o, *c* – thermal images and thermograms along the line of the opening *L* in the beginning and for 93 s of inductive activation of the sample. On thermograms, blue shows the distribution of the radiation temperature along the weld, taking into account the filtration of "high-frequency noise" (red color), which arise at the level of sensitivity of the microbolometer matrix of the infrared receiver of the thermal imager.

Dynamic indicators of sample temperature rise during activation:

– when heated by air, the temperature rise rate is 0.014 °C/s (from 20.4 to 24.5 °C);

– at induction heating, the temperature rise rate is 0.008 °C/s (from 24.2 to 24.9 °C).

As it is seen (Fig. 4, thermogram L_T on the thermal images a_o, c_o), at the moment of activation of the sample, the main effect on the temperature distribution along the weld seam through the section *L* changes the "relief" of the weld seam applied to it by paint and varnish coating (see Fig. 3) that change the radiating ability (ε) of the sample surface. At the same time, the change in the amplitude of the radiation temperature relative to the background temperature (for the thermal image a_o is 20.1 °C, for c_0 – 24.3 °C) does not exceed 0.1 °C. At the moment of maximum activation (see Fig. 4,a,c), the change in the radiation temperature amplitude on the "relief" of the weld relative to the background temperature (for *a* – 24.5 °C, for *c* – 24.7 °C), taking into account the heterogeneity of the sample's warming by activators, reaches 0.3 °C.

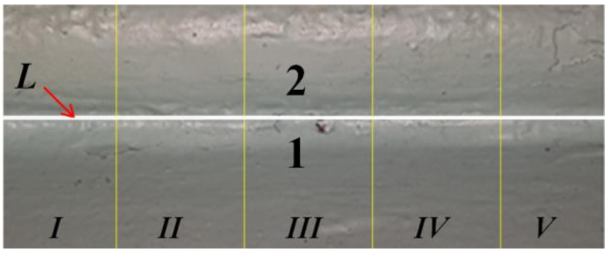


Fig. 3. Image of a fragment of a real product made on ferromagnetic steel (St. 30 – sheet steel (1) with a thickness of 4 mm and a pipe (2) – a diameter of 34 mm, a thickness of 4 mm, connected by a weld seam along the line L), located in the working zone thermal and induction activators. The traces of corrosion and weld on the surface of the product are hidden under a continuous multilayer paint and varnish coating

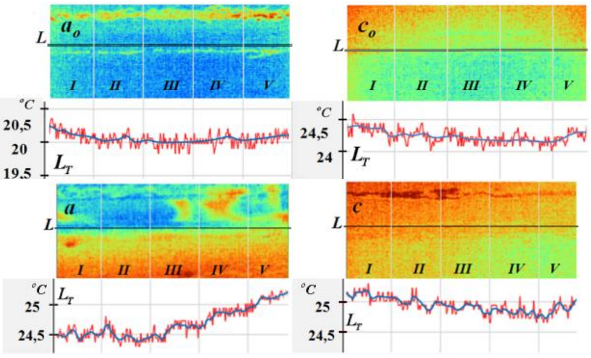


Fig. 4. Thermal manifestation of the weld in the working zone of activators along the line L for thermal and inductive activation of the sample (product) from the ferromagnetic material (St. 30). a_o, a – thermo-image and thermogram L_T along the line L in the beginning and for 290 s of thermal activation of the sample; c_o, c – thermo-image and thermogram L_T along the line L in the beginning and for 93 s of induction activation

The character of the distribution of thermoanomalities on the thermograms along the line *L* of the separation for both methods of activation coincides in zones I–V of the thermo-images of the sample with a sufficient degree of correlation for analysis.

The analysis of data from experimental studies shows that regardless of the method of activation (thermal or induction activation), the nature of the thermoforming of structural inhomogeneities on the thermoforming of a sample from a ferromagnetic material is practically identical and is determined by the thermodynamics of the process – the rate of heating of the sample, which depends on the energy power of the activator. Even at an insignificant rate (at the level of 0.008…0.014 °C/s) the temperature changes of the sample during the activation process, a significant increase (in 3 to 5 times) of the amplitude of thermal (structural) (relief) inhomogeneities of the weld is ensured.

CONCLUSIONS

1. The main condition for the use of thermal thermo-thermal monitoring of pipelines on nuclear-energy complex objects is the consideration of the objectively existing connection of the parameters of the external influence with the response to these effects of the characteristics of the material, which changes its parameters depending on the amplitude and frequency characteristics of the influence .

2. Significant potential for increasing the informativeness of thermographic methods involves the use of various physical mechanisms for activating the temperature field in the vicinity of the defective zone, in particular by selective heating of defective zones (with size 1 mm and more which situated on the near surface deep comparable with 1/3 of pipe walls) by the action of thermal or electromagnetic fields, using vibration of process equipment, transients during start-up or stop of equipment, cyclic and thermoelastic load as an activation source. In this case, the formation of information fields of IR radiation of objects of control occurs depending on the parameters of the activating fields, the properties of the material of the objects of study, their geometric sizes and the impact of the environment.

3. Identification of defects on the basis of dynamic thermography can be carried out according to the analysis of thermal images of objects of control, the interval of shooting time which can vary from minutes and hours to days, weeks, months. Particular attention should be paid to the analysis of the physical nature and description of background characteristics and their dependence on the thermal influence of external sources of activation. In many cases, the amplitude of the temperature of the false anomalies significantly exceeds the anomaly of latent defects, which requires application of thermal analysis of special processing methods that take into account temperature gradients and structural (morphological) features of thermoanomalies due to defective structures.

4. Effective differentiation of surface thermal anomalies into real and false, which in amplitude can significantly exceed the thermal defect detection, allows dynamic thermography. The analysis of the dynamics of thermal processes forming the temperature field in the defect area on the basis of the use of the normalized coefficient of thermal defect $K_{ТД}$ [11] takes into account the dynamics of change of the radiation and thermodynamic temperature at any point on the thermal image of the surface of the sample, which allows to identify the thermal defect detection against the background of false thermoanomalies.

5. Data of experimental researches confirm efficiency of use of thermal and low frequency electromagnetic activators in induction thermographic defectoscopy of ferromagnetic materials at activation time 10…100 s. In a large part of the thermal images analyzed in the studies, in a sufficiently explicit form it is possible to trace the reflection of the thermal appearance of hidden defects and false thermoanomalies, as well as the level of background radiation fluctuations. It allows to control the dynamics of thermal display of energy-absorbing structures, to identify the location of defects.

6. It should be taken into account that welded joints are more corrosion-resistant than the main material. The intensity of corrosion can be quite significant. The most dangerous is the development of corrosion cracking, in which there are rapidly developing superficial cracks. The effectiveness of detecting such cracks and localized corrosion, which is also rapidly evolving, can be greatly enhanced by the integration of visual and thermal imaging controls, which provide an overview of controlled surfaces in the visible (reflected reflection radiation) and infrared (own radiation of the surface of the object of control) spectra radiation. When thermovision control, surface cracks are clearly clearly manifested even in the background of areas with surface corrosion damage.

REFERENCES

1. N.I. Bazaleev et al. Teplovisionnyi monitoring tehnicheskogo sostoyaniya kompressornogo s energeticheskogo oborudovaniya kak metod effektivnogo resheniya problemy energosberesheniya // *Kompressornoye i energeticheskoe mashinostroenie.* 2006, N 1(3), p. 60-65 (in Russian).

2. E.M. Prokhorenko et al. Metal containing composition materials for radiation protection // *Problems of Atomic Science and Technology.* 2014, N 4(92), p. 125-129.

3. N.I. Bazaleev et al. Simulating the radiation transformations in rocks: potential media for radioactive waste disposal // *Physics of Particles and Nuclei letter*. 2009, v. 6, N 5, p. 417-423.

4. V.N. Volchenko. *Veroyatnost i dostovernost ocenki kachestva metalloprodukcii.* M.: “Metallurgiya”, 1979, 88 p. (in Russian).

5. A.V. Lykov. *Teoriya teploprovodnosti*. M.: “Vysshaya shkola”, 1967, 599 p. (in Russian).

6. L.I. Kudryashov. *Priblizhennye resheniya nelineynyh zadach teploprovodnosti*. M.: “Mashinostroeniye”, 1979, 232 p. (in Russian).

7. V.P. Vavilov. Informativnost teplovyh poley v zadachah aktivnogo kontrolya kachestva // *Defectoskopiya*. 1987, N 3, p. 67-77 (in Russian).

8. V.P. Vavilov. *Teplovye metody kontrolya kompozicionyh struktur i izdeliy radioelectroniki.* M.: “Radio i svyaz”, 1984, 152 p. (in Russian).

9. T. Ummenhofer, J. Medgenberg. Numerical modeling of thermoelasticity and plasticity in fatigue-loaded low carbon steels // *QIRT Journal*. 2006, v. 3, N 1, p. 71-91.

10. V.V. Kurepin. Pribory dlya issledovaniya temperaturoprovodnosti i teploemkosti v rezhime monotonnogo razogreva // *Izv. vuzov. Priborostroeniye*. 1966, v. 9, p. 127-130 (in Russian).

11. V.T. Uvarov et al. Radiation acoustic control over the thermal parameter of construction materials irradiated by intense relativistic electron beam // *Phys. of Part. and Nucl. Latter*. 2014, v. 11, N 3, p. 274-281.

12. M.I. Bazaleev et al. Zastosuvfnnya electromagnitnoi aktyvacii pry termografichnomu controli defective ta structurnyh neodnoridnostey v feromagnitnyh materialah // *Tehnicheskaya diagnostika i nerazrushayushiy control*. 2016, N 2, p. 50-60 (in Ukrainian).

13. N.I. Bazaleev, V.V. Lytvynenko. Thermographic defectoscopy of materials in nuclear energy based on the analysis of the normalized coefficient of the dynamics of thermoproduction of defects at induction activation // *Problems of Atomic Science and Technology*. 2018, N 5(117), p. 154-161.

14. N.I. Bazaleev et al. Thermovision acoustic thermo-graphy constraction materials defectoscopy // *Problems of Atomic Scince and Technology*. 2011, N 2(97), p. 178-185.

Article received 05.07.2019

ПРИМЕНЕНИЕ АКТИВНОЙ ТЕРМОГРАФИИ ПРИ ТЕПЛОВИЗИОННОЙ ДЕФЕКТОСКОПИИ ТЕХНОЛОГИЧЕСКОГО ОБОРУДОВАНИЯ НА ОБЪЕКТАХ ЯДЕРНО-ЭНЕРГЕТИЧЕСКОГО КОМПЛЕКСА

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Рассмотрены методические и физические основы применения активной термографии как высокопроизводительного неразрушающего метода контроля и дефектоскопии материалов при тепловизионном мониторинге технологического оборудования на объектах АЭС. Данные экспериментальных исследований подтверждают эффективность использования тепловых и низкочастотных электромагнитных активаторов в термографической дефектоскопии. Исследованы особенности термопроявления структурных неоднородностей и дефектов в материалах в динамической термографии. Показано, что применение специальных методов обработки термоизображений, учитывающих амплитудно-частотные и морфологические особенности термоаномалий, позволяет контролировать термопроявление энергопоглощающих структур и дефектов и обеспечивает возможность их идентификации на фоне ложных термоаномалий.

ЗАСТОСУВАННЯ АКТИВНОЇ ТЕРМОГРАФІЇ ПРИ ТЕПЛОВІЗІЙНІЙ ДЕФЕКТОСКОПІЇ ТЕХНОЛОГІЧНОГО ОБЛАДНАННЯ НА ОБ'ЄКТАХ ЯДЕРНО-ЕНЕРГЕТИЧНОГО КОМПЛЕКСУ

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Розглянуто методичні і фізичні основи застосування активної термографії як високопродуктивного неруйнівного методу контролю і дефектоскопії матеріалів при тепловізійному моніторингу технологічного устаткування на об'єктах АЕС. Дані експериментальних досліджень підтверджують ефективність використання теплових і низькочастотних електромагнітних активаторів у термографічній дефектоскопії. Досліджено особливості застосування динамічної термографії і впливу зовнішніх джерел активації на термопроявлення структурних неоднорідностей і дефектів у матеріалах. Показано, що застосування спеціальних методів обробки термозображень, які враховують амплітудно-частотні і морфологічні особливості термоаномалій, дозволяє контролювати термопроявлення енергопоглинаючих структур і дефектів та забезпечує можливість їх ідентифікації на фоні хибних термоаномалій.