THERMOGRAPHY IN UKRAINE: RANGES OF APPLICATION AND RESULTS

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Results of investigations of Research-Technical Centre "Thermocontrol" at Kharkov National University of Radioelectronics for recent years are presented.

Centre has the certification of the National Space Agency of Ukraine (NSAU) No 000084 on right to works in the field of space technology. Two experts of the III level on thermal control (IT) by ISO version work in its membership.

The main direction of research of Research-Technical Centre (RTC) for recent years is the popularization of thermographic method in Ukraine, where it is developed not enough. Power engineering, hydraulic engineering, gas-transfer equipment and house-building were considered as the main fields of application of this method.

Power engineering

Different facilities of power industry of some metallurgic enterprises of Ukraine are considered as the objects of thermography. As example, thermogram of bus isolation switch with uncovered developed defect, which can be the cause of accident and interruption of technological process, is shown in Fig.1.

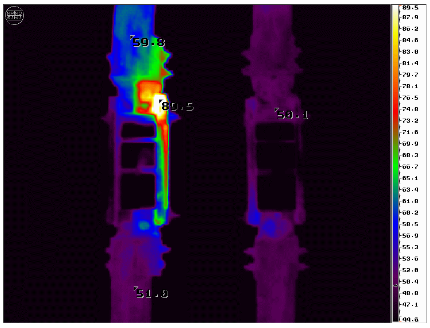

Fig. 1. Thermogram of bus isolator (RVR 2000/10) with emergency heating of electrical branch on 39ºC

In the Fig. 2, 3 the various transformers thermograms are shown. They are rather compound objects, because the main defects are located inside, and heat image is blurred at the expense of engine oil circulation in the system. The defects can be detected by indirect signs. For this, thermograms of tank surface are obtained in the places of location of winding bends, by tank height, tank bell fastening, cooling system and their elements etc. When thermogram processing, extreme branches and transformers of similar types temperature and their heating change dynamics with time and loading are compared; local overheating and its location are determined; places of heating are compared to magnetic conductor elements and windings location; cooling system work effectiveness is determined.

Obtained results support the availability of thermography use in power engineering.

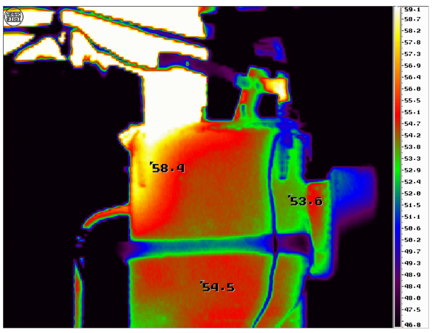

Fig. 2. The upper part of transformer EOCN-12000 tank heating in the place of low-voltage power bus line outlet

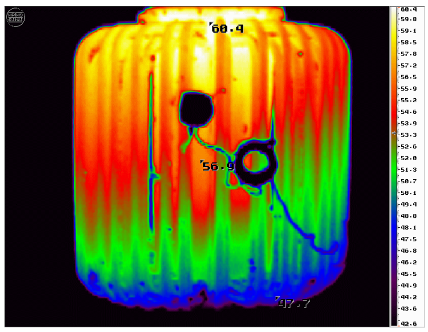

Fig.3. The thermogram of transformer TM-1200. Heterogeneity of temperature field ±6°C in the middle level about 54°C

Hydraulic engineering

The main part of hydraulic constructions (dams) in Ukraine is exploited already for decades and requires close control of technical condition. Along with traditional (regulated) means and methods, possibility of use thermography for this control is considered.

It is known, that heat evolution and fluctuations of external air temperature at gravitational dams construction cause the considerable temperature stress in concrete block and cracks initiation, which can considerably change the scheme of structural behavior of construction and decrease its load-carrying ability. Therefore nonequilibrium temperature field of dam body is one of the informative signs for evaluation of strength properties of hydraulic facilities.

Measuring of temperature field is carried out now by contact method with the help of sensors, located in the dam body. Realization of contact method requires considerable expenses of costs and time. Termographic method gives the possibility to register the temperature field of hydraulic objects by contactless way, which makes the control more operative, informative and efficient.

RTC «Thermocontrol» experts have carried out thermography inspection of the complex of Dnieper hydroelectric power station (HEPS) hydraulic constructions. Inspection consisted of internal and external thermography.

Objects of internal thermography were: upper gallery of weir dam; gallery of intake wall of HEPS-1; gallery of control room of HEPS-2.

Objects of external thermography were: intake wall of HEPS-1; weir dam; sluices of HEPS-2.

Internal thermography has shown that temperature field in the upper gallery and in the galleries of Dnieper hydroelectric power station dam is inhomogeneous. All parts of galleries have peculiarities in temperature fields, which can be their characteristic or peculiar passport.

Several sections with anomalous temperature are found in the upper gallery. The cause of such increased temperature is the higher temperature of percolating water.

Differences of water temperature in different sections can be explained by different rate of its penetration. So, revealed heat aperiodicities show certain level of crippling of dam body in respective plots.

External thermography included infrared survey of intake wall of HEPS-1 by scheme shown in Fig. 4.

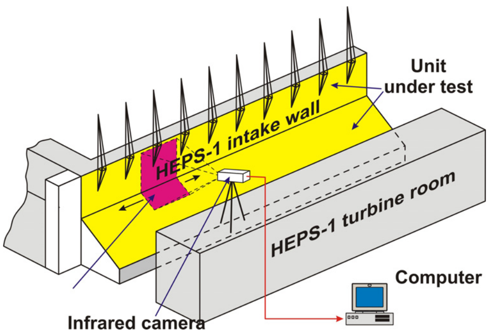

Fig.4 Scheme of external thermography of HEPS-1 intake wall

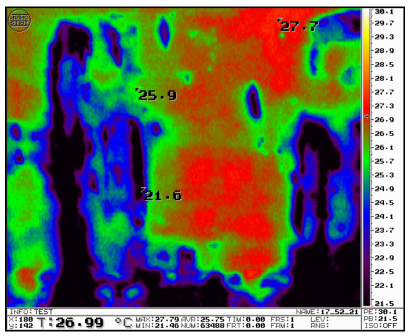

Fig. 5 Thermogram of the part of HEPS-1 intake wall (section of the 1st aggregate).

Surface condition of the HEPS-1 intake wall essentially influences on thermogram (Fig.5), but the borders of penetration are determined rather good. Moistening of construction joints which is not seen on visible images is visible on thermograms and it allows to use obtained data for the system of antifiltering measures development. Reiterated thermography inspection after the maintenance may show the quality of these works.

In consequence of thermography inspection the new important information about temperature regimes of hydraulic construction of Dnieper hydroelectric power station is obtained.

Productivity of thermography method and its informativity allows the hydraulic constructions heat passports development and their regular temperature monitoring carrying out.

The further directions of research can be the improvement of thermogram processing to increase their informativity and to create a database of all inspected objects.

Heat losses in the buildings

It is known, that the aim of the buildings thermography inspection is the thermal resistance of outer frame fillings indices determination and their power efficiency evaluation.

According to known techniques, it is necessary to obtain rather large amount of experimental data. They include not only thermography inspection results proper, but also information about the heat flows through walling and the inside temperature evaluation during 5…14 days.

As measuring equipment in such case not only infrared camera is used but also some other facilities (recording sensors of temperature, measuring device for heat flows etc.).

Such comprehensive approach allows in result to evaluate the quality of the building walling thermal isolation with rather high precision (with up to 15% error), but is rather labor-intensive and expensive.

Taking into account that application of this method is on the initial stage in Ukraine, we had an attempt to use the thermographic method of buildings inspection by simplified scheme.

Thereto the special method has been developed. Its essence is an obtainment of the relative heat loss of the building express-evaluation only by the thermographic inspection results, i.e. without measurement of heat flows and other additional parameters.

Suggested method is based on determination of relative heat loss factor η:

$$\eta = \frac{\sum_{i=1}^{n} S_i \left(T_i - T_a\right)}{S_{gen}\left(T_{av} - T_a\right)}, \qquad (1)$$

where S_{gen} is building surface area which gets to infrared image frame; S_i is overheated (comparing to T_{av}) surface areas; T_i is the temperature of these areas; T_a is ambient temperature; T_{av} is an average temperature of a surface in given image.

To determine η for the whole building it is necessary to carry out the thermography inspection of the whole outer surface of building (with division by images) and to register environmental temperature. This method was approbated by authors on several buildings. The example of thermogram of school building, obtained by infrared camera «IRTIS-200», is shown in Fig. 6. All obtained thermograms were processed by special program «ThermoSquare v.1.0». Using such data from thermograms as temperature T_i in every point (pixel), the program calculates values S_i, T_{av}, S_{gen} and determines η for each thermogram from formula (1), as well as for the whole building. Results of such processing can be visualized, as it is shown in Fig. 7, where the image areas with temperature over T_{av} are marked by the white colour.

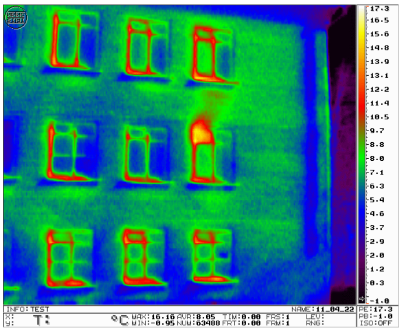

Fig. 6. Thermogram of the building walling area

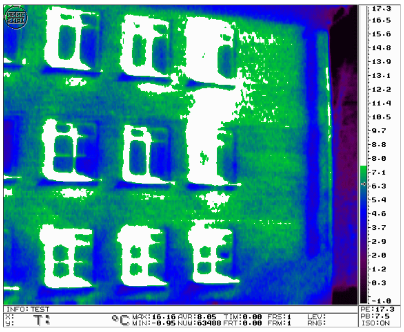

Fig. 7. Processed thermogram of the walling area

The practice shows that the values of the relative heat loss factor are different for various buildings. For example, for the school building of sixties with old windows η=60%, and for new administrative building with metal-plastic windows it is lower: η=40%.

Suggested approach to heat losses in buildings and constructions evaluation is really an express-method, because it gives the necessary estimation (in relative units) during short time with minimal costs.

Obtained during an inspection information provides not only integral evaluation of heat-insulating features of walls and windows of the building, but also allows to determine (identify) the places of the most intensive heat leakage.

Gas-transfer equipment

The condition of Ukrainian gas-transfer system as object of diagnostics is defined by the fact that considerable part of energy&mechanical equipment and particularly gas-transfer aggregates (GTA) has worked off the main part of its resource, and to prevent accidents and energy resources overrun it is necessary to carry out the regular diagnostics of their technical condition. Thermography usage for this purpose is reasonable, because the work of every aggregate unit is tracked by the heat emission, which produces certain temperature distribution (field) on its surface. Temperature values of some construction units and elements can be the diagnostic signs of their technical condition. Flawless unit condition is characterized by the rated temperature, when initiation and development of defects temperature grows, and under considerable defect it reaches the certain level, which shows the necessity of assuming some measures.

To solve the problem of defect identification it is necessary to introduce the criterion of defectiveness (decision rule). Known approaches to solution of this problem are based on the amplitude criterion (comparison of given points of surface temperature with the mean value for the whole surface).

However, measurement of temperature in the point (small number of pixels) is unavoidably accompanied by noise (influence by heterogeneity of surface properties, exposure from outside sources etc.). Therefore it is necessary to analyze the whole unit surface.

The temperature field of this part (in thermogram) analysis also should be carried out not by standard criterion (value of temperature), but by the certain statistic parameter.

For this purpose, the following thermogram processing method is suggested. On the thermogram of every unit (e.g., compressor cylinder (Fig. 8)) fields of interest are revealed. These areas are represented as a matrix with the values of every pixel of image intensity (which is equivalent to temperature) and are considered as samples to which statistical methods are applicable.

For every such area histogram (polygon of frequencies) and its envelope are built (Fig. 9).

Heights of the columns of histogram are proportional to the number of pixels, which get to the certain interval of values (here – intensity or respective temperature). Area of obtained histogram is equal to sample size.

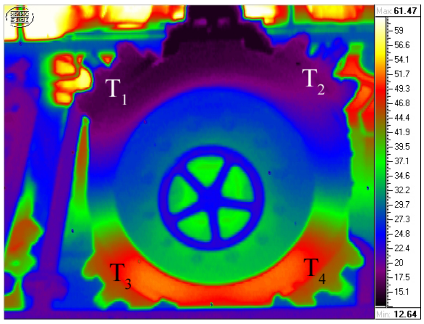

Fig. 8. Control temperature points (fields of interest) in the thermogram of compressor cylinder location:
T_1, T_2 – induction valves;
T_3, T_4 - delivery valves

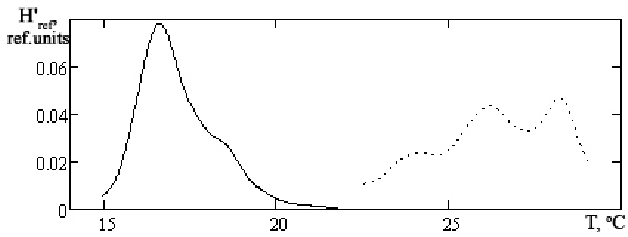

Fig. 9. Histograms envelopes of compressor cylinder induction valves. Defect valve histogram envelope is marked by dotted line

Histograms and their envelopes are compared by three parameters: shift, dispersion and the shape of distribution.

For gas-engine compressor units with rather big statistical sample the statistical approach has been developed. It is based on the comparison of obtained thermograms with reference by the integral similarity test I introduction:

$$I = (D1a)^2 + (D2)^2 + (D3)^2 . \qquad (2)$$

It considers the totality of informative signs, particularly, distribution of temperature, shape of image histogram and background contents.

Integral similarity test (2) contains in standard form such indices:

- modified criterion of the histogram shape comparison:

$$D1a = \sum_{i=1}^{N} \min\left(\left|H(i) - H_{ref}(i-1)\right|, \left|H(i) - H_{ref}(i)\right|, \left|H(i) - H_{ref}(i+1)\right|\right); \qquad (3)$$

- criterion of distinction by background contents:

$$D2 = \left|\Pr(H) - \Pr\left(H_{ref}\right)\right|; \quad (4)$$

- statistical criterion of Cramer&Welch:

$$D3 = \frac{\sqrt{nm}\left|\mu(X) - \mu\left(X_{ref}\right)\right|}{\sqrt{n\sigma^2(X) + m\sigma^2\left(X_{ref}\right)}}, \quad (5)$$

where $H(i)$ is the i-th element of analyzed thermogram histogram; $H_{ref}(i)$ is the i-th element of reference thermogram histogram; N is the number of thermogram decomposition elements; $\Pr(H), \Pr\left(H_{ref}\right)$ –the obtained histogram maximal peak of analyzed and reference images to the total number of points relation; $\mu(X), \mu\left(X_{ref}\right)$ – the expectancy of analyzed and reference images; $\sigma(X), \sigma\left(X_{ref}\right)$ – standard deviation of analyzed and reference images; $n \times m$ – image size.

As virtual reference (physical etalon is difficult to create) it is suggested to use averaged thermogram of units. The particular reference is created for each aggregate, because they differ by certain parameters as the temperature of supplied refrigerants, gas pressure etc.

As integral similarity test (2) has χ^2 distribution with two degrees of freedom (χ_2^2), critical value of integral criterion I_{cr} is taken from reference tables for χ^2 distribution. On the level of significance $\alpha = 0{,}05$ critical value of integral simulation criterion is equal to:

$$I_{cr} = 5{,}99. \quad (6)$$

Thus, the main rule is $I > I_{cr}$, that means that units which satisfy this condition are considered as defective ones.

For suggested method validity evaluation, its approbation was carried out by the real units of gas-engine compressors inspection results processing: 128 valves and 23 connecting-rod bearings. Errors of the first kind indirect evaluation gave the result 7,8% and 8,6% respectively, which does not go out the limits of specified significance level $\alpha = 0{,}05$ and is acceptable.

As the second object of gas-transfer equipment the **main gas pipelines** were considered. The aim of thermography use was the determination of liquid phase content.

It is known, that to increase the hydraulic efficiency and work security of gas pipelines, blasting and cleaning of their inner cavity are carried out, which takes considerable cost expenses. One of the ways to decrease these expenses is the obtaining of information about the gas pipeline contamination level, particularly, about contents of its liquid phase, by noncontact way.

To solve this task, it is suggested to use termography. To verificate this suggestion theoretical and experimental researches were carried out.

Experimental researches were to carry out the thermographic inspection of the part of gas pipeline. In Fig.10 the image of dug up gas pipeline part and its thermogram (after respective processing) are presented.

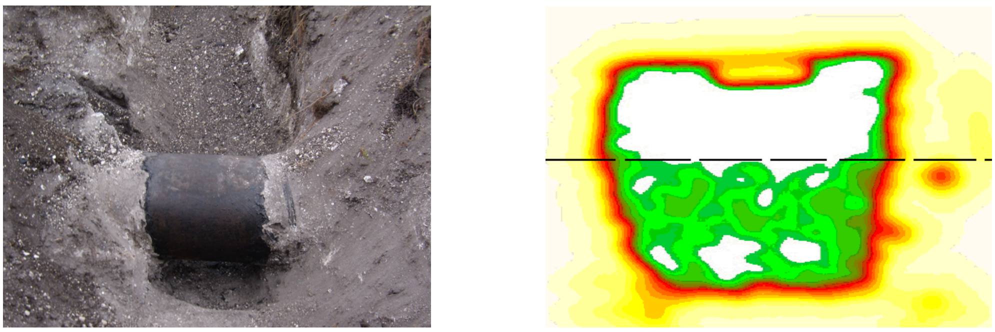

Fig.10. Visible image of the pipeline part and its processed thermogram. Dotted line shows the border of gas and condensate partition.

In the thermogram the border of temperature field partition between upper (gas) and lower (condensate) parts of pipeline are clearly seen; difference of temperatures was 0.6°C at environment temperature T_0=14°C and gas temperature T_1=16°C. Line of partition of temperature field can be interpreted as the level of filling the pipe with condensate, which amounts 60% of pipe volume.

For the experiment results analysis the thermalphysical model of gas pipeline with condensate, which scheme is shown in Fig. 11, was developed.

The results of temperature difference $\Delta T=T'_1-T'_2$ calculation on the pipe surface at constant gas temperature (T_1 = 16°C) and different environment temperature T_0 and condensate T_2 are presented in Table 1.

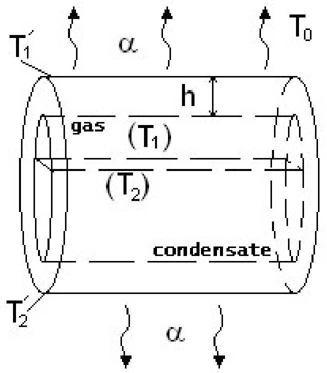

Fig. 11. Schematic model of pipeline

Table 1. Results of theoretical modeling

No of variant	Input data		Result
	T_0, °C	T_2, °C	ΔT, °C
1	14	14	0,7
2	14	15	0,5
3	0	0	9,3
4	0	5	7,5
5	-10	-10	12,2
6	-10	0	8,7

As can be seen from the Table.1, the result of calculations by the 1st variant according to conditions of experiment, comes closer to experimental value 0.6°C. Temperature difference ΔT essentially grows (to 12.2°C) at the difference between temperature of gas and environment increase.

Obtained experimental and calculated data confirm the principal possibility of the thermography method use for the condensate level in a gas pipeline determination. This method has such important advantages as contactless and quick-action.

Conclusions

The thermography use in Ukraine has essentially spread for recent years, however many problems require solution. They are standard base creation, expert training system organization, thermographic diagnostics methods development.

Further development of statistic methods of thermography information processing seems to be perspective (not only for Ukraine). It gives the possibility to pass from direct registration of an controlled object temperature field anomalies to the qualitatively new stage of non-destructive testing – to defects identifying and at last to industrial equipment technical condition diagnostics.