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THERMAL CONTROL FOR METAL CONDITION TESTING IN PIPELINES OF NUCLEAR POWER PLANT

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Abstract: The thermographic examination results of nuclear power plant high pressure pipelines and main condensate pipelines are considered. The conditions and technique of several sections thermal control are specified. It is found, that cavitation defects have a "heat trace". The use of thermography as an effective express-control method for quick determining the temperature anomalies space for a detailed study of other methods is proposed.

Key words: thermography, hidden defects, external factors, cavitation, high pressure steam lines, main condensate pipelines.

1. Introduction

In the course of operation, structural materials used in power engineering change their properties. It is the cause of defects that can lead to man-made accidents.

The high thermal loads experienced by thermal and nuclear power plants lead to a reduction in the thermal resistance of the metal. As a result, the temperature on the surface of equipment and pipelines rises. Therefore, the temperature is the most important diagnostic index.

The use of contact methods for determining metal condition is often a difficult task due to the size of the objects of control or the difficulties of access to them. The laboriousness of surveys can be significantly reduced when applying thermography. Currently, there are a large number of models of thermal imagers that are able to perform this task.

With regular thermographic monitoring by comparing the results, it is possible to assess the condition of the object, to identify defective areas and outline the ways to eliminate them.

In the world nuclear power engineering, the programs for nuclear power plants provide for up to 50 thousand test procedures, among which the role of thermovision monitoring is constantly increasing. In the US, the thermal testing method is used at all nuclear power plants. This method is used in some Russian nuclear power plants [1, 2].

The aim of research was to determine the locations of the alleged hidden defects for their subsequent detailed assessment by contact methods.

2. Methods and conditions of testing

The investigations were carried out on the pipelines of two blocks of the Zaporizhzhya NPP.

Two groups of objects with different thermal regime were tested:

- 1) High pressure steam pipes (carrier temperature up to 600 ° C);
- 2) Main condensate pipelines (carrier temperature about 30 ° C).

From the point of view of thermographic survey, the pipes are a complex object.

Even with a uniformly heated pipe and its uniform coating in closed rooms, there are effects, conditioned by a number of external factors, which significantly complicate the quantification of the parameters of hidden defects [3, 4]. Thermal testing was carried out in production facilities at a temperature of about 30°C. The lighting of the production facilities was in accordance with the general principles, the main of which is creation of a uniform level of illumination.

To link the survey results, a photographic survey of objects in the same angles as the thermal testing was carried out. Air temperature was measured near controlled objects.

Survey was regulated by technical requirements for work «Control of pipelines' metal and equipment of power units, using heat thermography» from 02.10.2007.

The places of thermal imaging were chosen according to the scheme, compiled on various types of metal wear of the working tract TU K-220-44, which was a conditional map, based on the experience of operation of saturated steam turbines.

The metal testing was carried out in accordance with PNAE G-7-008-89 "Rules for the Arrangement and Safe Operation of Equipment and Pipelines of Nuclear Power Plants", as well as on the basis of documentation for the thermal method of control, the results of scientific research and experience of STC "Thermocontrol" of KHNURE.

The thermographic testing was carried out on the sections of pipelines:

- without contact with the controlled object;

- without mechanical surface preparation;
- at the operating parameters of the equipment.

3. Results of research of high-pressure steam pipes.

Discovery of hidden defects in high-pressure steam pipes is of great practical interest. Positive results are obtained at thermal testing of open parts of objects, which temperature considerably exceeds air temperature. Characteristics of a stationary temperature field on a surface give the possibility to estimate the degree of metal thinning at the defect site [5].

However, according to the standards at thermal power plants, high pressure steam pipes are covered with a thermal insulation (fiberglass) and placed in a protective metal shield. Metal screens sometimes have an uneven, wavy surface. The temperature gradients of such a surface create on the thermograms a set of local thermal anomalies, which are not related to condition of the pipeline metal.

If the surface is sufficiently smooth, then diagnosis is possible. A sign of a developing internal defect is the temperature and area of the thermal anomaly (Table 1).

Thermography revealed the effect of "heat exposure" or the imposition of thermal fields. Temperature fields depend on relative location of objects, which must be taken into account when choosing the angle for thermal imaging.

Table 1. The temperature characteristics of the detected thermal anomaly.

Number of object	Area, cm ²	T _{max} , °C	T _{avr} , °C (surrounding area)	ΔT, °C (T _{max} - T _{avr})
4	260	57.1	50.5	7

The analysis of thermal images revealed, that tapping test equipment in pipelines are critical places for the appearance of temperature anomalies. In the course of the work, 6 fragments of high-pressure steam pipes were inspected. For objects of this type operating in the normal mode, the thermal insulation strongly distorts the temperature fields of the objects. Although the detection of hidden defects on this type of objects is difficult, thermal testing of critical sections (seams, frames) can give the possibility to reveal defects at the initial stages of their development.

4. Results of testing of main condensate pipelines

Hydrotechnical equipment is subjected to cavitation erosion. Cavitation erosion is caused by the phenomenon of cavitation that occurs in a moving fluid stream under certain hydraulic conditions. Erosion destruction of the surface during cavitation occurs due to repeated hydraulic impacts of liquid jets on the surface. Fragment of pipeline with defect due to cavitation wear is shown in Fig. 1.



Fig. 1 – Fragment of the pipeline with a cavitation cave (defect).

According to experimental facts, the rate of cavitation fracture of metal is 5000– 10,000 times higher than the rate of corrosion destruction. Although there is no generally accepted theory of cavitation, but according to some estimates, the pressure peaks at compression (or destruction) of the cavitation caverns reach 250 MPa and the temperature reaches 10⁴ K [6–8].

From this it follows that the places of cavitation caverns formation are localized sources of increased temperature and cavitation can have a "thermal trace".

This assumption was confirmed by examining the main condensate pipelines with a carrier temperature of about 40 °C. The surfaces of the pipes studied were uniformly colored and smooth, which approximated them by their radiative properties to the Lambert radiators..

The result of thermal imaging in closed rooms, when the temperature of the object is commensurate with the temperature of the ambient air, is greatly influenced by external factors. As a result of their action, zones with an imaginary ("induced") temperature are formed on the surface of objects, which does not correspond to the real radiation temperature of the object. In addition to quantita-

tive temperature differences, such induced anomalies also had distinctive qualitative features. The following types of factors influencing the temperature fields of objects were identified and studied:

- Influence of lightening;
- The influence of the shape of object surface;
- Influence of powerful external heat radiators;
- Influence of floor radiation.

The results of analysis are shown in Table 2.

As a result of the research, several objects were discovered that have hidden defects.

Figure 2 shows a fragment of the pipeline with the identified zone of cavitation erosion. This defect was found on the following grounds:

- The form of the defective zone is not regular and differs from the temperature distortions caused by the external factors studied;

- The defect position does not change when the shooting angle changes;

- The maximum defect temperature differs from the temperature of the rest of the pipe by 2.66°C, which exceeds the levels of other temperature anomalies (see Table 2).

The actuality of detection is supported by the fact that the detected defect is on the turn of the pipeline, where there is a sharp braking of the condensate flow, and such places are most likely for the occurrence of cavitation caverns. The result was confirmed by ultrasound testing.

Table 2. Qualitative and quantitative assessments of the influence of various factors

№	Factor	Qualitative differences, features	Levels of temperature anomalies
1	Lightening	The shape of areas with imaginary temperature repeats the form of glare from external light sources. Temperature anomalies have a characteristic position and depend on light sources location.	16...1.9 °C
2	Influence of the cylindrical shape of the object surface	The temperature anomalies are of a regular nature and position along the center of the object. The lower part of the pipe has, as a rule, a lower temperature.	1...1.7 °C
3	Influence of powerful external thermal radiators	Near the powerful thermal sources, a narrow zone with an elevated temperature appears in the upper part of the control facility. The temperature anomaly has a characteristic shape and position. Often the heat source gets into the frame.	0.9...1.8 °C
4	Influence of the floor of the room	The lower part of the pipe (up to the axial one) has a lower temperature. Temperature anomalies have a pronounced character and position.	0.55...1.0 °C

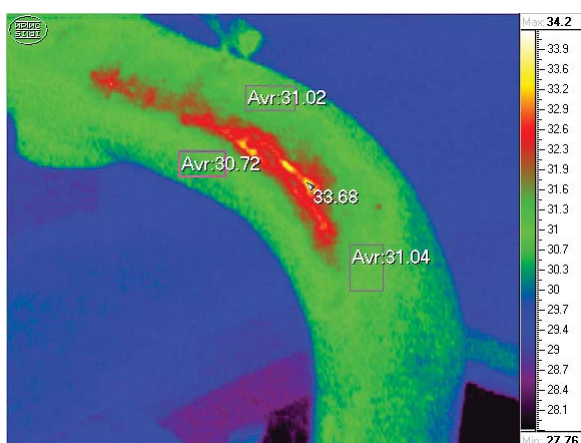


Fig. 2. The revealed zone of cavitation erosion (defect of pipe wall thinning).

5. Conclusions

Research has given a positive result and have shown the prospects of thermography for definition of metal condition in pipelines in thermal and nuclear stations.

To predict the life of pipelines, exact values for pipe thickness reducing are required, which can be obtained with the help of a contact US method. Analyzed external factors make it difficult to obtain accurate quantitative estimates that are necessary for predicting the residual resource of objects. The thermography makes it possible to quickly obtain information on the presence of metal defects during the pre-start period after preventive maintenance and during operation, revealing by temperature anomalies the area for detailed study by other, more accurate methods. This will save time, improve the quality and efficiency of control. Thermal testing will determine the areas of priority research in order to optimize the scope of control (planning the scope and timing of repair of equipment and pipelines based on their actual condition).

The laws of cavitation and the measures to prevent it have not been studied; therefore effective revealing the cavitation caverns in hydraulic equipment is very important. The use of an acoustic method for diagnosing cavitation defects in the elements of the flowing part of hydraulic systems is impractical, since it takes a long time, many times greater than detection by other methods. Therefore, the detection of a "thermal trace" during cavitation is an important result.

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