DIAGNOSTICS OF THERMAL PIPES WITH SYMMETRIC STRUCTURE THERMAL IMPACT METHOD

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Abstract: *On the basis of completed studies, including computer modeling of the morphology of the temperature field of heat pipes and thermal measurements in the framework of the experiment, a method was developed for diagnosing the quality of heat pipes with a symmetrical structure.*

KEYWORDS: diagnostics, heat pipe, temperature field, defect, visualization, simulation, thermal imaging system, isotherm.

1. Introduction

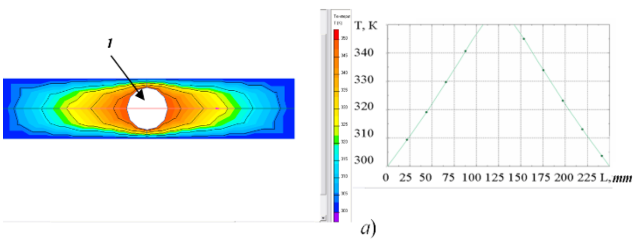
It is known that heat pipes (HP) historically belong to the class of special cooling devices and they can carry out high-speed transport of high-intensity heat flows beyond the localization of various heat sources within their own containment. Currently, HP’s are widely used in various ground-based, airborne and space-based electronic systems, as well as in nuclear power engineering and, of course, in computer technology [1-5]. Therefore, high demands arc made on the reliability of HPs, and the methods and means of diagnosing them arc constantly evolving and improving. It should be noted that, along with ultrasound and X-ray methods, a certain scientific and practical interest in the quality control of products in the containment, within which phase transitions take place with absorption and heat release, are thermal methods. The greatest efficiency, reliability and sensitivity among them have thermal imaging, [6,7]. Despite the fact that in the scientific literature there is information about thermal imaging techniques for monitoring various objects, including pipelines, their direct transfer for diagnosing HP is fraught with a number of difficulties. They are caused, for example, by the variety of materials used for the manufacture of shells, wicks, heat transfer fluids, design solutions, etc. The work is devoted to approbation of the developed technique, including the use of field characteristics, for diagnosing HPs.

2. Research methodology

Experimental studies were conducted on a laboratory bench containing an IR - television system (KTP-326Ekh camera based on an uncooled thermal imaging module IR-113, X = 8
thermal receivers: (IR - pyrometer - Mastech MS6530; thermocouple XA) and PC with software. As the objects of study were selected profile aluminum pipes. The heat carrier in them was acetone or ammonia. Theoretical studies (modeling in the ELCUT and COSMOS environment) were performed using the finite element method [8, 9].

3. Research results and discussion

Analysis of the literature showed that the design of the TT mainly uses approximate engineering methods of thermal calculation, for example,



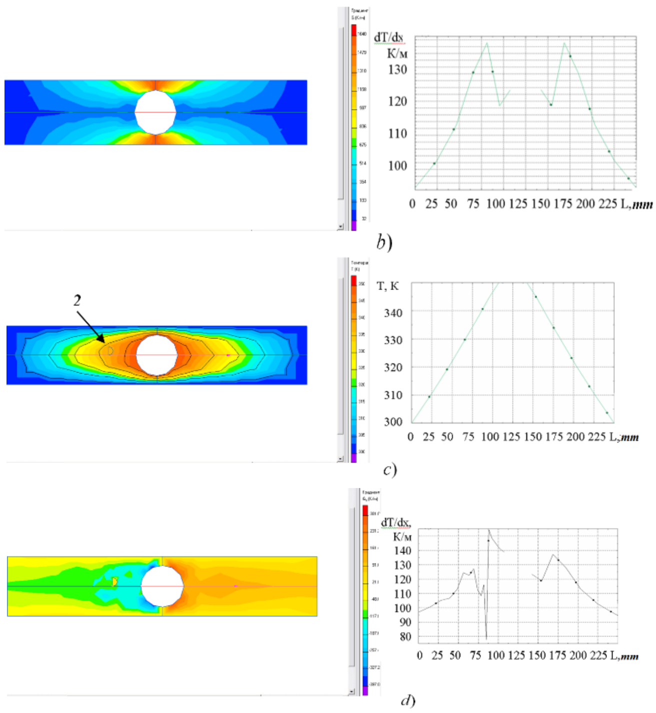


Figure 1 *- Features of the temperature field in an aluminum heat pipe. Method of field characteristics. Payment. (Pulsed Heat Source(PHS) operation time, τ = 100 s).*

a, *c - isotherms and temperature distribution along the selected circuit (1 - PHS; s -HP with defect: 2 - case defect, segment-air);*

b, *d - the field of temperature gradients and the distribution of the gradient along the selected contour (d-HP with a hull defect, segment-air).*

the basis of the theory of thermal circuits, and others. [1]. This is due to the complexity of accounting and descriptions of all phenomena occurring within the operating HP. As the initial thermal model of the profile HP, we have chosen the model of an anisotropic rod (Fig. 1) [1, 10]. A pulsed heat flow source (PHS) with insulated surfaces was located in the center on the surface of the rod. The studies used sources of round and rectangular shapes.

Taking into account the thermal inertia of the system, the maximum time of the PHS operation was x = 120 s. The thermal connection of the PHS with the HP surface was considered ideal. The original equation of heat conduction [10]:

(1) $$C_\rho \rho \frac{\partial T}{\partial t} = \lambda_x \frac{\partial^2 T}{\partial x^2} + \lambda_y \frac{\partial^2 T}{\partial y^2} + \lambda_z \frac{\partial^2 T}{\partial z^2} + q_0$$

where: *Cp* and p is the specific heat capacity and density of the material; *Xx, Xy, Xz* - thermal conductivity coefficients; ***q0*** - heat output per unit volume of sources of thermal energy; T is temperature; x, y, z - coordinates; within the framework of the formulated constraints, it was solved numerically (finite elements of a triangular shape were used) on a PC in the standard "ELCUT" environment.

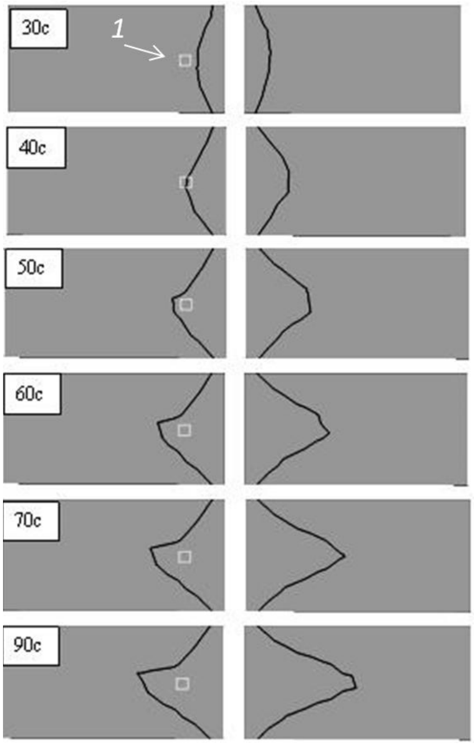


Figure 2 - *Changing the shape of the isotherm in time when there is a rectangular shape (air) in the body of the defect (1). Example: Aluminum HP, rectangular PHS. Calculation (isotherm scale, 90K).*

When constructing a mathematical model, initial and boundary conditions (of the first and third kind) [10], obtained from targeted experiments, were used:

1. At the initial moment of time, for the edges of all bodies included in the model, the temperature was constant:

(2) Ti,τ = 0 = Ta = const

2. For all PHS edges, taking into account the isothermality of the surface, a condition of the first kind was set:

(3) T=Tp

On the edges of the HP model, a third kind conditions was specified, which in describes both convective and radiant heat exchange with the environment:

(4) $$\lambda_p \frac{\partial T}{\partial n} = -\alpha_k(\text{T-Ta}) - \beta(T^4\text{-}T_a^4)$$

Where: β - is a value equal to the product of the Stefan-Boltzmann constant (σ0 = 5.7 ▪ 10-8 W $/m^2/K^4$) and the coefficient of radiation of the surface of the probe material; α_k- convection heat transfer coefficient. Heat flow diversion through conductive connections of HP fixture was not considered.

Qualitative analysis of the temperature field by color pictures, the shape and nature of the distribution of isotherms in HP allowed us to identify the following features (Fig. 1). The location of the PHS in the central part of the HP without a defect generates both the left and the right of the source a symmetrical structure of isothermal lines, as well as a symmetrical temperature distribution relative to the selected circuit (Fig. la). The specified value of the anisotropy of the thermal conductivity coefficient *X\ / Xy* = 40 led to the formation of isothermal lines with pointed tops. The nature of the temperature gradient change relative to the selected contour (Fig. lb) also emphasized the symmetric structure of the thermal field.

It is known that the magnitude and speed of transfer of heat flux in the HP depends on many factors, among which a significant role belongs to the defects of the wick structure, the body [1-3]. Most often, these defects may appear due to the imperfection of the HP manufacturing technology, and also be acquired during operation. Pores, cracks in the body of the HP significantly reduce the degree of tightness, and in terms of vibrations, shock can lead to early failure of the HP. Modeling the temperature fields of the HP with defects made it possible to understand the basic laws of change in the field characteristics, and therefore prepare the basis for the development of a diagnostic technique. Defects of regular geometric shape were chosen as the model: round, in the form of a segment, rectangular, triangular. The main variable physical characteristics of the defects were the thermal conductivity coefficient, as well as the density and specific heat capacity. Examples of simulation results of such systems are shown in Fig. lc, d and Fig. 2. It can be seen quite well that along with the change in the shape of isotherms, symmetry breaking with respect to the HP center, a defect with a low thermal conductivity coefficient most strongly changes the field of the temperature gradient.

3.2 Experimental studies

To create a pulsed local heating, a film resistive heater was used, which, through heat conductive paste (KPT-8), was attached to the IIP strictly in the center. Getting the original brightness contrast (image) was carried out with a horizontal position of the HP (on the edges), and to reduce the methodological errors, heat is removed from the surface of the pipe on both sides of the PHS occurred under conditions of free convection. It should be noted that well-known measures were taken, including shielding to reduce external illumination.

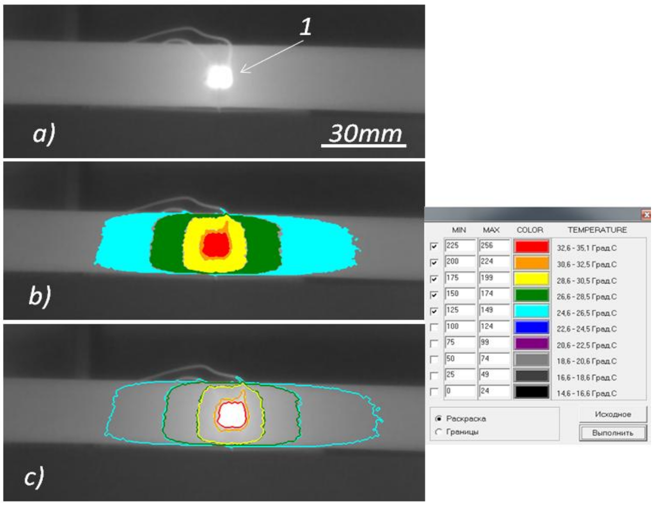


Figure 3 - *Visualization of the thermal field of an acetone heat pipe using the "Parus 5.0" program. Example. A photo. Experiment: (heating time, T = 45 s). a - the initial thermal brightness brightness contrast (1 - PHS); b - structure of thermal field zones (Thermogram mode, pseudo-coloring); c - evolution (slip) of isotherms (isoline mode).*

The transition from the image to the quantitative characteristics of the thermal state of the HP was implemented using the method of field characteristics (MFC) in the form of the developed universal software (software) ’’Parus 5.0” [11]. It allowed to carry out image input (static and dynamic - video) both from a television camera via a video signal input board in a PC, and from a file in the "* .bmp” format. A typical example of visualization is shown in Fig.3. Considering that the experiment used a commercially available HP, without specially introduced defects, in the framework of this technique we can only talk about the features of the morphology of this temperature slice. The focal nature of its structure, which most likely can be associated with surface defects of the HP body, is quite clearly visible. And the asymmetry is most pronounced in the nature of the temperature distribution, relative to the PHS (it is difficult to transport heat to the left side of the IIP). It is clear that to establish the true causes of the asymmetry effect require additional research.

3. Conclusions

The method of the field characteristics, based on digital thermal imaging processing algorithms, allows you to create criteria for assessing the quality of the heat pipe.

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