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NONDESTRUCTIVE TESTING FOR DIAGNOSTICS OF PIPELINES

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Thermal methods of nondestructive testing are widely used for the analysis of the thermal insulation of underground pipelines. In heat methadone nondestructive testing, the thermal energy is distributed in the test object. Temperature field of the object's surface is a source of information on the characteristics of heat transfer. This article describes the modifications we have developed some of the heat flux sensors. A common element of these devices is the battery thermoelectric sensor special design, acting as a thermoelectric converter heat flow.

Keywords: heat flux, heat flux sensors, thermal radiation detectors, heat sensor metric.

Thermal methods of nondestructive testing are widely used for different kinds of protective coatings for the analysis of the thermal insulation of underground pipelines, in oil and gas industry, house-building, etc.

Violation of thermal insulation leads to a change of temperature on the surface of the coating. Conclusion about the state of thermal insulation can be made on the basis of data of the surface temperature of insulation and temperature field inside the studied object [1].

One of the main structural units of the automatic system for the experimental investigation of thermal processes is a unit for the measurement of thermal processes [2]. Requirements for complex sensors, built the block, are defined by the basic parameters of the processes investigation. The basis of the unit contents specially designed heat flux sensors, heat detectors, which allow measurements of local and average parameters of thermal processes under stationary and non-stationary conditions.

Among the various applications of the heat flux sensors the control of the state of thermal insulation of pipes with coolants has a special place. Such control can be done by measurement of heat losses with primary thermoelectric converter heat flow, heat detector and electronic unit for conversion of signal. The main lack of these devices is the dependence of their data from accidental changes of the environment.

To solve the problems, we have developed several versions of the heat flux sensors, whose indications are independent from changes in the environment [2, 3]. A common element of these devices is the special designed battery of thermoelectric sensors, acting as a thermoelectric converter heat flow. Thermoelectric sensor is designed as a finite cylinder, whose one base is the work surface, and the second one has the thermal contact with the body of environmental temperature. Built-in heaters can create heat flow through a thermoelectric sensor in the direction perpendicular to its bases [3].

In one of the versions of the thermal flow sensor "active" junctions of thermoelectric converter are in thermal contact with the receiving plate, and "passive" junctions contact with a heating element, the temperature of which is controlled by temperature-dependent element. This design allows you to combine the function of two heat-flow units in one. During the preparation of the device the receiving plate is put in thermal contact with the test object in the place with absence of defects in thermal insulation. Electrical current is passed through the heating element and its value must be such that the signal at the output of the thermoelectric converter would be constant. This means that the heating element generate a reference heat flaw through a thermoelectric converter that is equal in magnitude and opposite in direction to heat flow from the test object in the field of thermal insulation defects. In the investigation of possible defects in insulation the current through the heating element is not regulated. This leads to a change in the signal at the output of the thermoelectric converter of the heat flow. The magnitude of the changing allows appreciate the degree of thermal insulation defects.

In another variation of the heat flux sensor the heating element is replaced with thermoelectric refrigerator, "cold" junctions are embedded in the radiator, and "hot" one is in thermal contact with the thermoelectric converter of a heat flow. Through the thermoelectric refrigerator the electric current is passed with a value which gives the zero as the output signal of the thermoelectric converter if the receiving plate is in contact with the investigated object in the absence of defects in the thermal insulation. Thus, the heat flux that produced by the thermoelectric cooler in the direction of a thermoelectric converter is reference one. With these data the heat fluxes in areas where in thermal insulation defects have places are compared.

In the third modification of the heat flux sensor the heating element serves as a receiving plate simultaneously. This modification implies the calibration method of substitution of the heat flow from the investigated object by one from a heating element under passing an electric current trough it.

The proposed devices can operate as with a single channel scheme so with a dual channel one. Detecting anomalously high values of energy losses indicate the section of a pipeline with fully or partially damaged thermal insulation or mechanical damage of the pipe material.

The aim of the investigation is to study the heat sensor operating for diagnostics of pipelines. The main element of this heat sensor is the laminated sensitive element of battery type (Figure 1). Heat flow through the protective film 1 goes to the sensor 2. The hot junctions of the thermal batteries have thermal contact with a protective film and the cold junctions with thermal stabilizer 3. In this case, the role of thermal stabilizer performs massive body transferred the heat flow through the bottom of the housing 4 to the radiator 5. To eliminate the heat transfer from the flank surface the sensor element is surrounded by a heat insulator 6. The entire system is closed with a conical lateral surface 7.

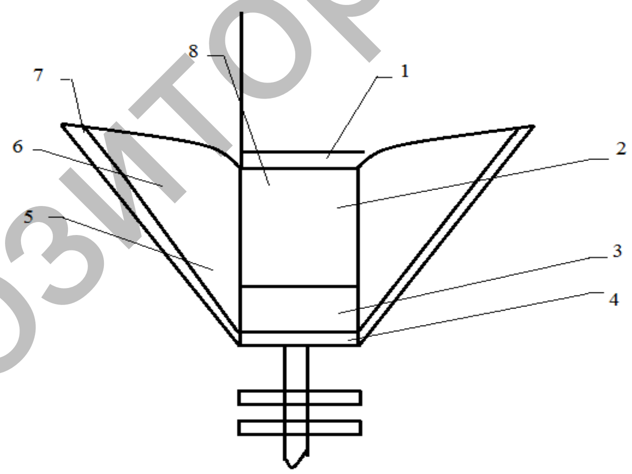

Fig. 1. Schema of the heat sensor: 1 – protective film, 2 – sensor, 3 - thermal stabilizer, 4 - bottom of the body, 5 – radiator, 6 - heat insulator, 7 – flank surface, 8 - gauge coils.

As a model of a sensor element, let's consider homogeneous limited cylinder.

Let the function q (r, t) describes the dependence of the heat flux, directed on a base of the cylinder, from the radius r and time t. The function $q_v(r,z,t)$ describes the dependence of the power of internal sources (W/m^2) from the radius r, the height z and time t. The heat exchange has place between all the surface of the cylinder and the environment variable temperature T_c(r,z,t) due to the Newton's law [4].

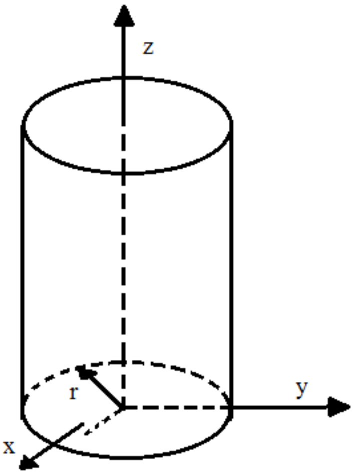

Fig.2. Schema of a sensor element.

The heat equation and boundary conditions in this case for a cylinder with radius R and height 1 will be next:

$$\frac{1}{a}\frac{\partial T(r,z,t)}{\partial T}=\frac{1}{r}\frac{\partial}{\partial r}\left[\ \frac{\partial T(r,z,t)}{\partial T}+\frac{\partial^2 T(r,z,t)}{\partial z}\ \right]+\frac{q_v(r,z,t)}{\lambda} \qquad (1)$$

$$T(r,z,l)=f(r,z) \qquad (2)$$

$$\lambda\frac{\partial T(R,z,t)}{\partial z}=-\alpha_R\left[T(R,z,t)-T_c(R,z,t)\right] \qquad (3)$$

$$\lambda\frac{\partial T(r,l,t)}{\partial z}=\alpha_l\left[T(r,l,t)-T_c(r,l,t)\right] \qquad (4)$$

$$\lambda\frac{\partial T(r,o,t)}{\partial z}=-\alpha_0\left[T(r,o,t)-T_c^*(r,o,t)\right] \qquad (5)$$

where $T^*_c(r,o,t)$ - the equivalent temperature of the environment:

$$T_c^*(r,o,t)=T_c(r,o,t)+q\frac{(r,t)}{\alpha_0} \qquad (6)$$

$\alpha_R, \alpha_0, \alpha_1$ are the coefficients of heat transfer from the environment to the lateral surface of the cylinder with the z = 0 and z = 1, respectively.

To solve the boundary problem (1) - (5) we will use the method of finite integral Hankel transformations with respect to r:

$$\overline{T}(\mu_n, z, t)=\int_l^R rJ_L\left(\mu_n\frac{r}{R}\right)T(r,z,t)\partial r\,, \qquad (7)$$

where $J_l\left(\mu_n\frac{r}{R}\right)$ is the Bessel function of a zero order, μ_n are roots of the equation:

$$\frac{J_l\,(\mu)}{J_1\,(\mu)} = \frac{d}{Bi_R} \quad (8)$$

in which $Bi_R = \alpha_R R/\lambda$.

Then let’s apply the finite neutral transformation of the general form o to the variable z:

$$u(\mu_n, b_k, t) = \int_0^1 \overline{T}(\mu_n, z, t) K(b_k z) dz\,, \quad (9)$$

where K (b_k, z) is the core of the transformation. Let’s put

$$K(b_k, z) = \cos\frac{b_k}{l} z + \frac{Bi_l}{b_k}\sin\frac{b_k}{l} z\,, \quad (10)$$

where $Bi_l=\alpha_1 1/\lambda$.

It is easy to show that the coefficients must satisfy the next equation:

$$ctgb_R = \frac{b_k^2 - Bi_L Bi_0}{b_k(Bi_L + Bi_0)}, \quad (11)$$

where $Bi_0=\alpha_0 1/\lambda$.

Inversion formulas for finite integral transformations (7) and (9) are, respectively:

$$\overline{T}(\mu_n, z, t) = \sum_{k=1}^{\infty} \frac{u(\mu_n, b_k, t) K(b_k z)}{\int_0^1 K^2(b_k, z) dz}\,, \quad (12)$$

$$T(r,z,t) = \frac{2}{R^2}\sum_{n=1}^{\infty}\overline{T}(\mu_n, z, t)\frac{\mu_n J_l\left(\mu_n \frac{r}{R}\right)}{\left(Bi_R^2 + \mu_n^2\right) J_l^2(\mu_n)}\,. \quad (13)$$

Making the transition from the image to the original formulas (12) and (13) we obtain the desired expression

$$T(r,z,t) = \frac{4}{R^2}\sum_{n=1}^{\infty}\sum_{n=1}^{\infty} c_k \frac{\mu_n J_l(\mu_n \frac{r}{R}) K(b_k, z)}{\left(Bi_R^2 + \mu_n^2\right) J_l\,(\mu_n)} \times \left\{ \exp\left[\left(-a\frac{\mu_n^2}{R^2} + \frac{b_k^2}{l^2}\right)t\right] \int_0^l \int_0^R f\left(r, z, J_l\left(\mu_n \frac{r}{R}\right)\right) \times \right.$$

$$\times K[b_k, z] drdz + \frac{a}{\lambda}\int_0^t \exp\left[-a\left(\frac{\mu_n^2}{R^2} + \frac{b_k^2}{l^2}\right)(t-\tau)\right] \times \left[\ a_0 K_{(b_k, 0)} \int_0^R \left(T_c(r,o,t) + \frac{q(r,\tau)}{a_{1_1}} r J_l\left(\mu_n \frac{r}{R}\right)\right) dr + \right.$$

$$+\ \alpha_l K(b_k, l) \int_0^R T_C(r,l,t) r J_l\left(\mu_n \frac{r}{R}\right) dr + \int_0^1 \alpha_R R J_l\,(\mu_n) \times$$

$$\left. \left. \times T_c(R,z,t) + \int_0^R r J_1(\mu_n \frac{r}{R}) q_v(r,z,t) dr) \times K(b_k, z) dz\ \right] d\tau\ \right\}, \quad (14)$$

where

$$\frac{1}{c_k} = 1 + \left(1 - \frac{Bi_l^2}{b_k}\right)\frac{\sin^2 b_k}{2b_k} + \left(2\sin^2 b_k + Bi_i\right)\frac{Bi_1}{b_k}. \qquad (15)$$

The solution (14) describes the temperature distribution in a limited solid cylinder with the boundary conditions (2) - (5). Let's consider the special case solutions. Let

$$T(r,z,o) = T_c = const,$$
$$\theta(r,z,t) = T(r,z,t) - T_c,$$

if the surface density of the absorbed radiation flux and internal sources of power q (r, z, t) depend on time, they can be represented as:

$$q(t) = q_0 F(t)$$
$$q_v(t) = q_{vo} F(t)$$

The expression for the excess temperature can be written as follows:

$$\theta = (r,z,t) = \frac{4d}{lR^2\lambda}\sum_{m=1}^{\infty}\cdot\sum_{k=1}^{\infty}\frac{c_k\mu_n^2 J\left(\mu_n \frac{r}{R}\right)}{\left(Bi_R^2 + \mu_n^2\right)J_0^2(\mu_n)} \times$$
$$\times\left(\cos\frac{b_k z}{l} + \frac{Bi_0}{B_n}\sin\frac{b_k z}{l}\right)\times\int_0^t \exp\left[-d\left(\frac{\mu_n^2}{R^2} - \frac{b_k^2}{l^2}\right)(t-\tau)\times\right]\times$$
$$\times\left[q_0 F(t)\left(\cos\frac{b_k z}{l} + \frac{Bi_0}{b_k}\sin\frac{b_k z}{l}\right)\int_0^R rJ_0\left(\mu_n \frac{r}{R}\right)dr + q_{v0}F(\tau)\int_0^l\int_0^R rJ_l\left(\mu_n \frac{r}{R}\right)dr \times\right.$$
$$\left.\times\left(\cos\frac{b_k z}{l} + \frac{Bi_0}{B_k}\sin\frac{b_k z}{l}\right)dz\right]d\tau\Big]$$

Consider the case of internal and external heating. When q(t) = 0, i.e. when internal (by current) heating has place, the temperature field of the cylinder is described by:

$$\theta = (r,z,t) = \frac{4qv_0}{cp}\sum_{n=1}^{\infty}\sum_{k=1}^{\infty}\frac{c_k Bi_R J_0\left(\mu_n \frac{r}{R}\right)}{b_k J_0(\mu_n)\left[Bi_R^2 + \mu_n^2\right]} \times$$
$$\times\left(\sin b_k + \frac{2Bi_0}{b_k}\sin^2\frac{b_k}{2}\right)\left(\cos\frac{b_k z}{l} + \frac{Bi}{b_k}\sin\frac{b_k z}{l}\right)P(t),$$

where

$$P(t) = \int_0^t F(\tau)\exp\left[-d\left(\frac{\mu_n^2}{R^2} + \frac{b_k^2}{l^2}\right)(t-\tau)\right]d\tau.$$

When the external heating (radiation) has place, that is $q_v(t)=0$, the excess temperature is given by:

$$\theta=(r,z,t)=\frac{4q}{lcp}\sum_{n=1}^{\infty}\sum_{k=1}^{\infty}\frac{c_k Bi_k J_0\left(\mu_n \frac{r}{R}\right)}{b_k J_0(\mu_n)\left[Bi_R^2+\mu_n^2\right]}\times$$

$$\times\left(\cos b_k + Bi_i \sin b_k\right)\left(\cos\frac{b_k z}{l}+\frac{Bi_0}{b_k}\sin\frac{b_k z}{l}\right)P(t).$$

Thus, the approach proposed in this paper has allowed to consider the temperature field of the device sensor described here in the different cases of heating. This device can be used in the sensor unit under automated experimental research of some particular processes.

For the purpose of testing of the method in the laboratory conditions the temperature field of wooden shield with sizes 1500x2000x20 mm, heated by radiation from the opposite side of the muffle furnace (t = 400^0C), located from the shield at a distances of 2 m and 4 m. On the shield was applied the grid with the step of 200 mm. The measurements were carried out at the nodes. The dependence of the relative radiometer signal (the ratio of the current signal to the maximum one) in respect to the coordinates of the grid is shown in Fig 3.

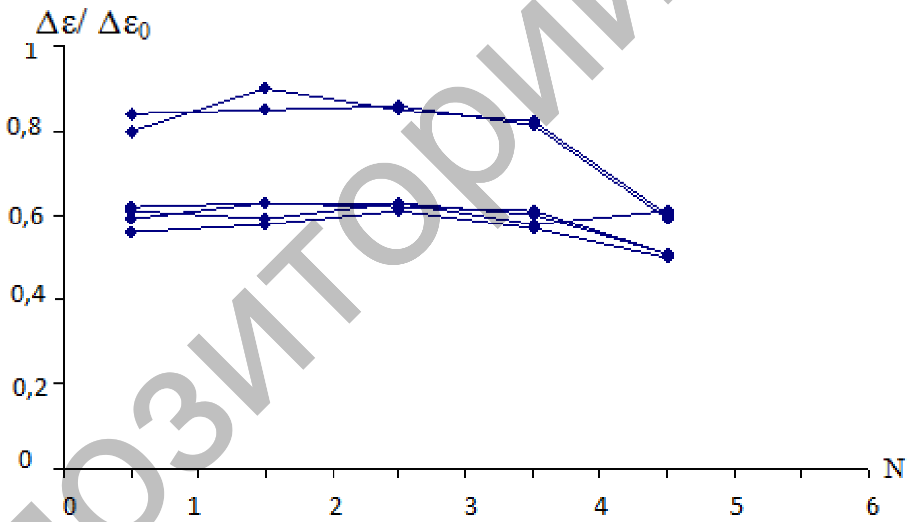

Fig.3. Dependence of relative signal of heat sensor on the coordinates.

On the horizontal axis are number of points from left to right. The numbers on the curves correspond to the number of horizontal lines from the top to the bottom of the shield. The measurements confirm the potential possibility to use the proposed heat sensor for realization of the nondestructive heat control method.

REFERENCES

1. Antipov Y.N. Measurement of pulsed light. – Karaganda, 1981. – 94 p.
2. AS 27617 RK 1999. A device for measuring heat flow. Antipov Y.N, Karabekova D.Zh.
3. AS 37716 RK 2001. A device for measuring heat flow. Kussaiynov K. Gladkov V.E., Karabekova D.Zh.
4. Antipov Y.N., Karabekova D.Zh., Akhtanova M.K., Imanasova N.V. Instruments for measuring the energy performance of thermal processes KSTU news Kaliningrad. - 2005.- № 7. p.241-245.

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