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INFLUENCE OF AIR GAP BETWEEN THE TRANSFORMER OF RESISTANCE AND OBJECT OF MONITORING ON TEMPERATURE MEASUREMENT ERROR

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Abstract. In operation the description of the developed heattransfer model in thermotransformers of resistance (RTD) in the conditions of air gap between surfaces of the sensor and object of measurement is provided. Research of influence of thickness of air gap on the relative error of temperature measurement by platinum, copper and nickel thermotransformers of resistance in the ranges of temperatures corresponding to each type is executed. Dependences of minimum necessary duration of heating up of sensors on the taken temperatures are received.

1 Introduction

Monitoring systems and regulations of temperature on production play an important role. Quality of operation of such systems directly depends on reliability of the measuring information received from sensors of the bottom level of systems therefore the accuracy of gages should pay special attention. At the bottom level measurement of technological parameters is performed by the sensors set directly on control objects. In a production activity one of the parameters of technological processes which are most often measured by such sensors is temperature. This parameter defines quality of course of technological processes, an equipment status, safety of production in general.

For temperature measurement and a signal transmission on distance in industrial conditions the wide circulation along with thermoconjugate sensors (thermocouple) was received by thermotransformers of resistance (RTD) [1, 2]. The principle of their action is based on dependence of electrical resistance of metal on temperature [1–4]. Often temperature is not only an index of efficiency of course of technological process, but also a safe criterion of operation of the equipment. Not full thermal contact with a work environment or a surface of object of measurement, namely air gaps [5, 6] can be one of temperature measurement error origins contact sensors. In this case increase of accuracy can be promoted by correction of conditions of execution of measurements or determination of optimum duration of execution of measurements which will be enough for receiving authentic results [5, 6].

The purpose of the real operation is development of model of a sensitive element of the thermotransformer of resistance and numerical research of a measurement error in different conditions of thermal contact of the sensor with object of measurement or a work environment.

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2 Physical model of heat transfer

Is considered 1 diagram of area of the solution of the task of heat conduction which is representing the non-uniform system and including a metal sensitive element (copper, platinum or nickel), aluminum oxide powder, a protective cover and air gap given on fig.

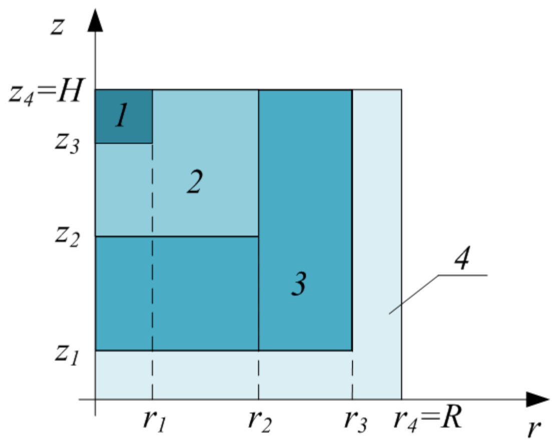

Figure 1. The diagram of area of the solution of the task of heattransfer in the RTD sensitive element: on outline borders boundary conditions of the II sort 1 – the RTD sensitive element are set; 2 – aluminum oxide powder; 3 – protective cover; 4 – air.

In case of the solution of the task the assumptions which aren't superimposing essential restrictions on a problem definition community are accepted:

1) heatphysical characteristics of elements of area of the decision don't depend on temperature;
2) the sensitive element has the correct cylindrical form.

The initial temperature of system “a sensitive element – the powder Al_2O_3 – a protective cover – air” corresponds to reference conditions and makes 20 °C. The model assumes process of temperature measurement of the surface of object separated from RTD by air gap.

As an index of the end of process of heating up an achievement moment by a sensitive element of temperature other than temperature on decision area boundary on the value which isn't exceeding the allowed measurement error which values are given in table 1 is chosen.

Table 1. Values of the allowed RTD temperature measurement error [7].

RTD type	Relative blundered, °C
Ni (C tolerance class)	$\pm(0{,}3 + 0{,}008 \cdot t)$ in the range of temperatures from 0 to 180 °C; от -60 до 180 °C
Pt (C tolerance class)	$\pm(0{,}6 + 0{,}008 \cdot t)$ in the range of temperatures from -100 to 300 °C; от -260 до 1100 °C
Cu (C tolerance class)	$\pm(0{,}5 + 0{,}0065 \cdot t)$ in the range of temperatures from -200 to 200 °C; от -200 до 200 °C

For area solutions of the task (fig. 1) are made the following sizes: H=5 mm; R=5 mm.

3 Mathematical model and decision methods

Process of heattransfer in the considered system (fig. 1) is described by system of differential equations:

$$c_1\rho_1\frac{\partial T_1}{\partial t}=\lambda_1\left(\frac{\partial^2 T_1}{\partial r^2}+\frac{1}{r}\frac{\partial T_1}{\partial r}+\frac{\partial^2 T_1}{\partial z^2}\right),\ t>0,\ 0<r<r_1,\ z_4<z<H \quad (1)$$

$$c_2\rho_2\frac{\partial T_2}{\partial t}=\lambda_2\left(\frac{\partial^2 T_2}{\partial r^2}+\frac{1}{r}\frac{\partial T_2}{\partial r}+\frac{\partial^2 T_2}{\partial z^2}\right),\ t>0,\ 0<r<r_2,\ z_2<z<z_3,\ r_1<r<r_2,\ z_3<z<H \quad (2)$$

$$c_3\rho_3\frac{\partial T_3}{\partial t}=\lambda_3\left(\frac{\partial^2 T_3}{\partial r^2}+\frac{1}{r}\frac{\partial T_3}{\partial r}+\frac{\partial^2 T_3}{\partial z^2}\right),\ t>0,\ 0<r<r_3,\ z_1<z<z_2;\ r_2<r<r_3,\ z_2<z<H \quad (3)$$

$$c_4\rho_4\frac{\partial T_4}{\partial t}=\lambda_4\left(\frac{\partial^2 T_4}{\partial r^2}+\frac{1}{r}\frac{\partial T_4}{\partial r}+\frac{\partial^2 T_4}{\partial z^2}\right),\ t>0,\ 0<r<r_4,\ 0<z<z_1;\ r_3<r<r_4,\ z_1<z<H \quad (4)$$

Where r – radial coordinate, m; z – axial coordinate, m; ρ – density, kg/ м3; c – specific heat capacity, J / (kg · °C); λ – coefficient of heat conduction, W / (m · °C); indexes: 1 – thermocouple's junction, 2 – powder of an oxide of aluminum, 3 – a protective cover, 4 – air.

Boundary conditions on inner and outline borders are given in the table 2.

Table 2. Boundary conditions of the task of heattransfer with the given external heat flux and boundary heat exchange.

Edge conditions	Decision area boundary	Edge conditions	Decision area boundary
"Sensitive element – powder Al_2O_3" ($r=r_1$, $z=z_3$)			
$T_1(r_1,z)=T_2(r_1,z)$; $-\lambda_1\left.\frac{\partial T_1}{\partial r}\right\vert_{r=r_1}=-\lambda_2\left.\frac{\partial T_2}{\partial r}\right\vert_{r=r_1}$	($z_3<z<H$);	$T_1(r,z_3)=T_2(r,z_3)$; $-\lambda_1\left.\frac{\partial T_1}{\partial z}\right\vert_{z=z_3}=-\lambda_2\left.\frac{\partial T_2}{\partial z}\right\vert_{z=z_3}$	($0<r<r_1$);
"Poweder Al_2O_3 – protective cover" ($r=r_2$, $z=z_2$)			
$T_2(r_2,z)=T_3(r_2,z)$; $-\lambda_2\left.\frac{\partial T_2}{\partial r}\right\vert_{r=r_2}=-\lambda_3\left.\frac{\partial T_3}{\partial r}\right\vert_{r=r_2}$	($z_2<z<H$);	$T_2(r,z_2)=T_3(r,z_2)$; $-\lambda_2\left.\frac{\partial T_2}{\partial z}\right\vert_{z=z_2}=-\lambda_3\left.\frac{\partial T_3}{\partial z}\right\vert_{z=z_2}$	($0<r<r_2$);
"protective cover – Air" ($r=r_3$, $z=z_1$)			
$T_3(r_3,z)=T_4(r_3,z)$; $-\lambda_3\left.\frac{\partial T_3}{\partial r}\right\vert_{r=r_3}=-\lambda_4\left.\frac{\partial T_4}{\partial r}\right\vert_{r=r_3}$	($z_1<z<H$);	$T_3(r,z_1)=T_4(r,z_1)$; $-\lambda_3\left.\frac{\partial T_3}{\partial z}\right\vert_{z=z_1}=-\lambda_4\left.\frac{\partial T_4}{\partial z}\right\vert_{z=z_1}$	($0<r<r_3$);
Edge statements of the task			
$\frac{\partial T}{\partial z}=0$	($z=H$);	$\frac{\partial T}{\partial r}=0$	($r=0$);
$T=Tr$	($z=0$);	$T=Tr$	($r=R$).

The solution of the task is executed by method of finite differences on the basis of the four-dot implicit difference diagram [8]. The area of the solution of the task represents a grid 200×200 nodes with steps of 2,5•10-2 mm on axial and radial coordinates, a step on dt time = 0,001 sec [8].

4 Results and discussion

Mathematical modelling were carried out at parameters [9, 10]: sensitive element RTD (type Pt): λ_1=70 W/(m·ºC); C_1=134 J/(kg· ºC); ρ_1=21500 kg/m^3; sensitive element ТПС (type Cu): λ_1=390 W/(m· ºC); C_1=385 J/(kg· ºC); ρ_1=8890 kg/m^3; sensitive element RTD (type Ni): λ_1=92 W/(m· ºC);

C_1=500 J/(kg· ºC); ρ_1=8900 kg/m^3; powder Al_2O_3: λ_2=6,57 W/(m· ºC); C_2=850 J/(kg· ºC); ρ_2=1520 kg/m^3; metal cover: λ_3=47 W/(m· ºC); C_3=850 J/(kg· ºC); ρ_3=1520 kg/m^3; air: λ_4=0,026 W/(m· ºC); C_4=1190 J/(kg· ºC); ρ_4=1,161 kg/m^3.

Dependences of a measurement error of temperature on sufficient time of heating up of a sensitive Pt, Cu, Ni element in case of different air gaps are shown in figures 2–4.

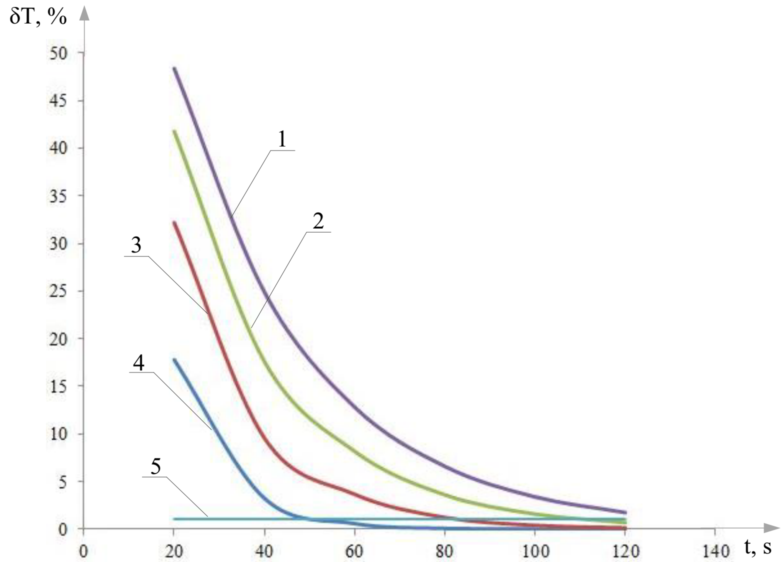

Figure 2. The dependences of a measurement error of temperature on time of heating up of the Pt type RTD sensitive element corresponding to values of thickness of air gap: 1 – 2 mm; 2 – 1,5 mm; 3 – 1 mm; 4 – 0,5 mm; 5 – admissible error.

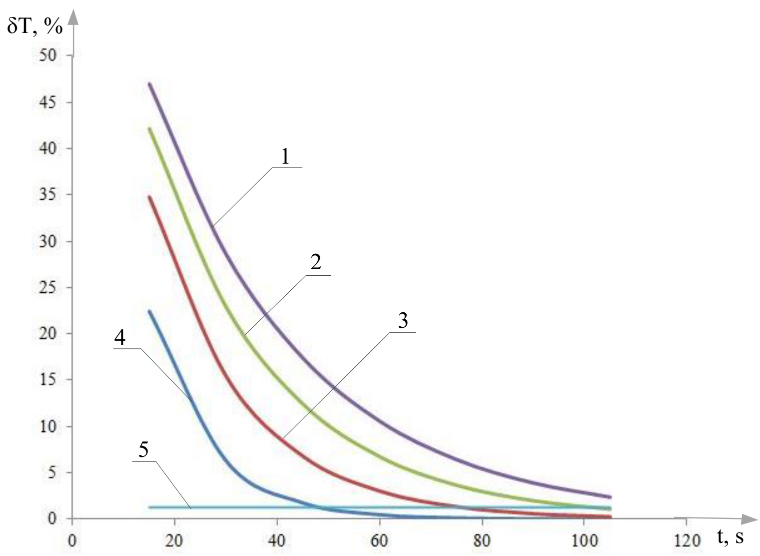

Figure 3. The dependences of a measurement error of temperature on time of heating up of the Cu type RTD sensitive element corresponding to values of thickness of air gap: 1 – 2 mm; 2 – 1,5 mm; 3 – 1 mm; 4 – 0,5 mm; 5 – admissible error.

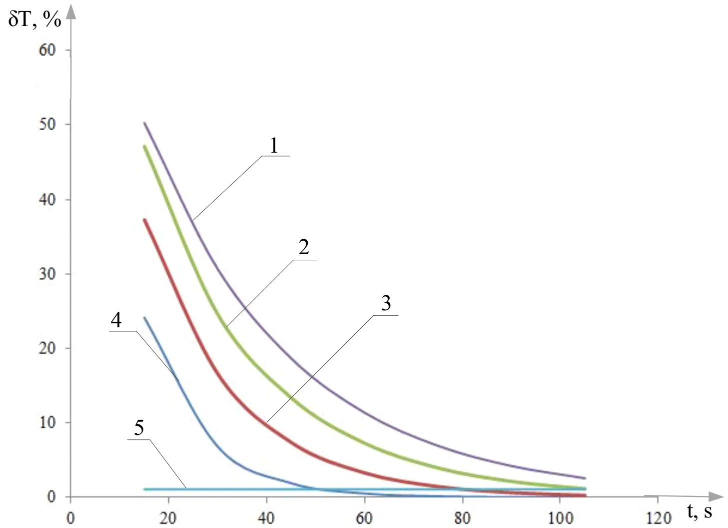

Figure 4. The dependences of a measurement error of temperature on time of heating up of the Ni type RTD sensitive element corresponding to values of thickness of air gap: 1 – 2 mm; 2 – 1,5 mm; 3 – 1 mm; 4 – 0,5 mm; 5 – admissible error.

The analysis of fig. 2 allows to draw a conclusion that with increase in duration of heating up the error of measurements non-linearly decreases. So, for RTD Pt type at a thickness of air gap of 0,5 mm of 50 seconds of heating up of the sensor will be enough for receiving results with a margin error, not exceeding the permissible deviations defined according to [7]. Researches showed that the increase in thickness of air gap between RTD and object of measurement causes increase of necessary time of heating: on 1 mm, on average, – by 1,6 times, on 1,5 mm – twice, and on 2 mm – by 2,5 times.

Similar dependences are received for copper and nickel thermotransformers of resistance. So, for copper RTD in the conditions of air gap 0,5 mm thick for receiving results within blundered the sufficient duration of execution of measurement makes 45 seconds, and for nickel RTD – 55 seconds.

During research dependence of duration of heating up of the RTD sensitive element on the taken temperature was also defined at the fixed thickness of air gap – 1 mm (tab. 3).

Table 3. Dependences of necessary duration of operation of TPS in case of temperature measurement.

Temperatyre *Tx*, ºC	Duration of operation of RTD, sec		
	Type *Pt*	Type *Cu*	Type *Ni*
50	42,122	45,957	44,250
75	52,170	56,029	54,239
100	58,017	61,891	60,018
125	62,027	65,914	63,961
150	65,014	68,910	66,884
175	67,353	71,257	69,164
200	69,248	73,159	71,004

From table 3 it is visible that dependence of sufficient duration of heating up of RTD non-linearly increases with increase in temperature. On average, the greatest time of heating is required for platinum RTD, the smallest – for copper that is caused by heatphysical characteristics of materials of the sensor.

5 Conclusion

The developed heattransfer models in the RTD sensitive element allow to predict sufficient measurement execution duration. Results of numerical researches show that temperature measurement error non-linearly decreases with increase in time of heating up of the sensor and can be lowered to the required level. It is set that the increase in thickness of air gap between the sensor and the controlled environment can lead to the multiple increase of a measurement error which can be lowered by increase in duration of execution of measurements.

Acknowledgments

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