MATEC Web of Conferences 23, 01017 (2015)
DOI: 10.1051/matecconf/20152301017

NUMERICAL RESEARCH OF THE MEASUREMENT ERROR OF TEMPERATURE THERMOCOUPLES WITH THE ISOLATED SEAL

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Abstract. Mathematical models of heattransfer are developed for an assessment of measurement errors of temperature by thermocouples with an isolated and uninsulated seal. Dependences of necessary time of heating (for authentic measurement) for the thermocouples with an isolated seal manufactured of different materials are set. It is shown that for thermocouples with isolated seal minimum necessary duration of heating up slightly exceeds this index for thermocouples with an uninsulated seal.

1. Introduction

Measurements in management systems play an important role since on their basis all processes connected to correction of operation of technology equipment are executed. The key parameters characterizing technological processes on production, as a rule, are temperature and pressure. Therefore the accuracy of measurements of these parameters should pay special attention. Besides, the accuracy of measurements often influences not only quality of regulation and control of technological processes, but also safety of operation of the equipment [1,2]. Depending on the range of the taken temperatures and the required level of accuracy of measurements in systems of measurement and regulation thermocouples and resistance temperature detectors can be used. The condition of thermal contact, construction of the thermocouple, and also duration of execution of measurements have a great influence on the accuracy of contact measurements [3–6].

In the real operation models of thermocouples with an isolated and uninsulated seal are developed; results of numerical research, executed by means of these models are given.

2. Physical model of heat transfer

The area of the solution of the task represents the non-uniform system "a thermocouple seal – a ceramic cap – powder – a protective cover – air" which geometrical representation is given in fig. 1.

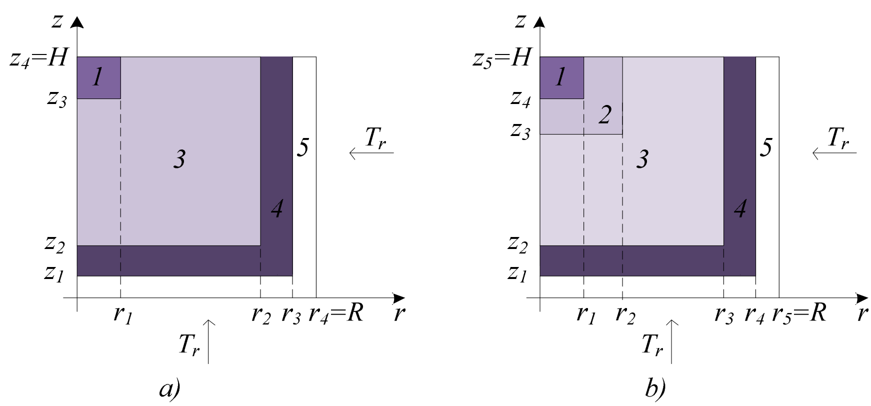

Figure 1. Area of the solution of the task: 1 – thermocouple junction, 2 – insulating cap; 3 – poweder Al2O3; 4 – metal cover; 5 – air

In case of the solution of the task it is accepted that heatphysical characteristics of elements of area of the decision don't depend on temperature.

The decision of the task of heat conduction was passed taking into account that the initial temperature of system corresponds to reference conditions and makes 20 °C, and heating up produced from the surface separated from the thermocouple by air gap. A condition of the end of heating up achievement serves as a thermocouple junction of temperature which will differ from the taken temperature on the value which isn't exceeding admissible a deviation for this type of the thermocouple.

For the thermocouple of the S type blundered in the researched range of temperatures it is constant and makes 1,5 °C, for the thermocouple of L type in the range of temperatures -40… 300 °C blundered make ±2,5 °C, in case of measurement of temperatures in the range 300 … 800 °C the permissible deviation is defined by dependence ±0,0075t °C. The thermocouple of K type in the range -40 … has 375 °C blundered ±1,5 °C and ±0,004t in the range of temperatures 375 … 1000 °C [8].

The sensitive element of the typical thermocouple has the cylindrical form with a diameter of 5 mm, height of the modelled section of the thermocouple is accepted 5 mm from the lower bound.

3. Mathematical model

The two-dimensional model of heattransfer (fig. 1) is described by the differential equations given in table 1.

Table 1. Mathematical model

№ i/s	For area (fig. 1, a)	For area (fig. 1, b)
	Heat conduction equations	
(1)	$c_1\rho_1 \frac{\partial t_1}{\partial t} = \lambda_1\left(\frac{\partial^2 t_1}{\partial r^2} + \frac{1}{r}\frac{\partial t_1}{\partial r} + \frac{\partial^2 t_1}{\partial z^2}\right),$ $t>0,\ 0<r<r_1,\ z_3<z<H$	$c_1\rho_1 \frac{\partial t_1}{\partial t} = \lambda_1\left(\frac{\partial^2 t_1}{\partial r^2} + \frac{1}{r}\frac{\partial t_1}{\partial r} + \frac{\partial^2 t_1}{\partial z^2}\right),$ $t>0,\ 0<r<r_1,\ z_4<z<H$
(2)	$c_3\rho_3 \frac{\partial t_3}{\partial t} = \lambda_3\left(\frac{\partial^2 t_2}{\partial r^2} + \frac{1}{r}\frac{\partial t_3}{\partial r} + \frac{\partial^2 t_3}{\partial z^2}\right),$ $t>0,\ 0<r<r_2,\ z_2<z<z_3$ $t>0,\ r_1<r<r_2,\ z_3<z<H$	$c_2\rho_2 \frac{\partial t_2}{\partial t} = \lambda_2\left(\frac{\partial^2 t_2}{\partial r^2} + \frac{1}{r}\frac{\partial t_2}{\partial r} + \frac{\partial^2 t_2}{\partial z^2}\right),$ $t>0,\ 0<r<r_2,\ z_3<z<z_4$ $t>0,\ r_1<r<r_2,\ z_4<z<H$
(3)	$c_4\rho_4 \frac{\partial t_4}{\partial t} = \lambda_4\left(\frac{\partial^2 t_4}{\partial r^2} + \frac{1}{r}\frac{\partial t_4}{\partial r} + \frac{\partial^2 t_4}{\partial z^2}\right),$ $t>0,\ 0<r<r_3,\ z_1<z<z_2$ $t>0,\ r_2<r<r_3,\ z_2<z<H$	$c_3\rho_3 \frac{\partial t_3}{\partial t} = \lambda_3\left(\frac{\partial^2 t_3}{\partial r^2} + \frac{1}{r}\frac{\partial t_3}{\partial r} + \frac{\partial^2 t_3}{\partial z^2}\right),$ $t>0,\ 0<r<r_3,\ z_2<z<z_3$ $t>0,\ r_2<r<r_3,\ z_3<z<H$
(4)	$c_5\rho_5 \frac{\partial t_5}{\partial t} = \lambda_5\left(\frac{\partial^2 t_5}{\partial r^2} + \frac{1}{r}\frac{\partial t_5}{\partial r} + \frac{\partial^2 t_5}{\partial z^2}\right),$ $t>0,\ 0<r<L,\ 0<z<z_1$ $t>0,\ r_3<r<R,\ z_1<z<H$	$c_4\rho_4 \frac{\partial t_4}{\partial t} = \lambda_4\left(\frac{\partial^2 t_4}{\partial r^2} + \frac{1}{r}\frac{\partial t_4}{\partial r} + \frac{\partial^2 t_4}{\partial z^2}\right),$ $t>0,\ 0<r<r_4,\ z_1<z<z_2$ $t>0,\ r_3<r<r_4,\ z_2<z<H$
(5)		$c_5\rho_5 \frac{\partial t_5}{\partial t} = \lambda_5\left(\frac{\partial^2 t_5}{\partial r^2} + \frac{1}{r}\frac{\partial t_5}{\partial r} + \frac{\partial^2 t_5}{\partial z^2}\right),$ $t>0,\ 0<r<L,\ 0<z<z_1$ $t>0,\ r_4<r<R,\ z_1<z<H$
	Boundary conditions	

(6)	$T_i(r_i,z)=T_{i+2}(r_{i+2},z);$ $-\lambda_i \frac{\partial T_i}{\partial r}\Big\vert_{r=r_i} = -\lambda_{i+2}\frac{\partial T_{i+2}}{\partial r}\Big\vert_{r=r_{i+2}}$, i=1	$T_i(r_i,z)=T_{i+1}(r_{i+1},z);$ $-\lambda_i \frac{\partial T_i}{\partial r}\Big\vert_{r=r_i} = -\lambda_{i+1}\frac{\partial T_{i+1}}{\partial r}\Big\vert_{r=r_{i+1}}$, i=1…5
(7)	$T_i(r_i,z)=T_{i+1}(r_{i+1},z);$ $-\lambda_i \frac{\partial T_i}{\partial r}\Big\vert_{r=r_i} = -\lambda_{i+1}\frac{\partial T_{i+1}}{\partial r}\Big\vert_{r=r_{i+1}}$, i=2…5	
(8)	$r=0,\ \frac{\partial T}{\partial r}=0$	$r=0,\ \frac{\partial T}{\partial r}=0$
(9)	$z=0;\ T=T_r$	$z=0;\ T=T_r$
(10)	$z=H;\ \frac{\partial T}{\partial r}=0$	$z=H;\ \frac{\partial T}{\partial r}=0$

Here r – radial coordinate, m; z – axial coordinate, m; c – specific heat capacity, J/(kg·°C); ρ – density, kg/m^3; λ – coefficient of heat conduction, W/(m·°C); indexes: 1 – thermocouple junction, 2 – protective cap; 3 – powder of an aluminum oxide, 4 –protective cover, 5 – air.

Initial conditions difine the temperature distribution in the thermocouple's sensitive element in an initial time point:

$t=0;\ t=t_0$, 0<r<R,

$t=0;\ t=t_0$, 0<z<H,

where t_0=20 °C – temperature corresponding to reference conditions.

Boundary conditions of heat transfer problem solution domain are defined as follows.

Boundary conditions of the first kind are set on r=R boundary: r=R, t=$t_р$, where t_r – temperature of a heating element.

4. Solution Procedures

The area of the solution of the task (fig. 1) is broken into the uniform grid consisting of 240 nodes. The slot pitch on radial and axial coordinates is equal 2,5•10^{-2} mm. The step on a temporal grid changed in the range from 10^{-4} to 10^{-2} with for reduction of volume of computation and increase of accuracy of the decision.

Systems of equations (1)–(5) with the appropriate initial and boundary conditions decided using a method of finite differences. The solution of the difference analogs of the differential equations representing the linear algebraic equations was carried out by a local and one-dimensional method. The pro-race method on the basis of the implicit four-point diagram [9] was applied to the decision of system of the difference equations.

5. Results and discussion

Thermal and physical characteristics of elements of one-dimensional and two-dimensional heat transfer problem solution domain are presented in Table 2.

Table 2. Thermal and physical characteristics of materials [10–11]

№	Material name	Heat conduction	Specific heat	Density

materi al		coefficient λ, W / (m·J)	capacity with, J / (kg·J)	ρ, kg/m^3
1	Thermocouple junction (type *L*)	24.75	713	8920
1	Thermocouple junction (type *K*)	33.1	768	8825
1	Thermocouple junction (type *S*)	50.4	139	20710
2	Ceramic case	16	1050	3800
3	Powder Al_2O_3	6.57	850	1520
4	Protective cover Steel	15	462	7900
5	Air	0.026	1190	1.161

Dependences of duration of heating up of thermocouples on the taken temperature with an isolated seal for K and L thermocouples taking into account existence of air gap of 1 mm are given in fig. 2.

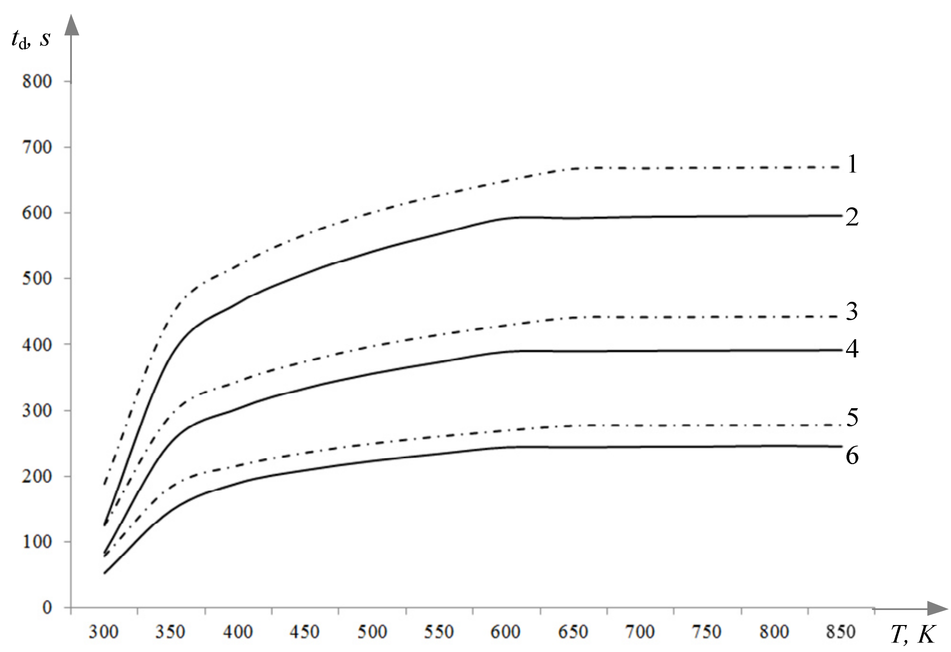

Figure 1. Dependence of duration of heating up of the thermocouple on the taken temperature for different values of air gap for the thermocouple of K type and L type: L type: 2 – 3 mm; 4 – 2 mm; 6 – 1 mm; K type: 1 – 3 mm; 3 – 2 mm; 5 – 1 mm

The analysis of fig. 2 shows that with increase in temperature heating up duration non-linearly increases and for the thermocouple of K type slightly exceeds heating up time for the thermocouple of L type, in case of temperature measurement more than 600 K heating up duration practical doesn't change. Besides, the size of air gap between the thermocouple and the heater increases heating time for 1 mm on average by 1,5 times, and by 2 mm – by 2,4 times.

Values of duration of heating up of thermocouples with an isolated and uninsulated seal in the conditions of existence of air gap 1 mm thick are given in table 3.

Table 3. Duration of heating up of thermocouples with different construction

The token temperature	Type L		Type K		Type S	
	Uninsulated seal	Isolated seal	Uninsulated seal	Isolated seal	Uninsulated seal	Isolated seal
300	49,976	52,437	74,801	78,411	72,379	75,336
350	150,959	158,030	176,060	184,360	170,492	177,230
400	181,285	189,740	206,470	216,180	199,956	207,820
450	199,748	209,045	224,990	235,550	217,894	226,450
500	213,061	222,996	238,340	249,510	230,828	239,880
550	223,479	233,859	248,780	260,440	240,951	250,400
600	232,963	243,776	257,370	269,430	249,268	259,032
650	233,377	243,678	264,400	276,780	256,327	266,360
700	233,692	244,539	264,710	277,110	262,459	272,730
750	233,939	244,797	264,960	277,370	267,880	278,360
800	234,303	246,006	265,160	277,580	272,737	283,410
850	234,506	245,178	265,320	277,750	277,138	287,980

Follows from table 2 that for the thermocouples having an isolated seal, heating up duration slightly exceeds minimum necessary duration of heating up for thermocouples with an uninsulated seal: for 4,6% – for K and L thermocouples and for 3,9% for the thermocouple of S type.

6. Conclusion

The description of the two-dimensional mathematical models describing heattransfer in case of temperature measurement by thermocouples with an isolated and uninsulated seal is provided in operation. Based on the executed numerical research it is possible to draw the following conclusions:

1) Existence and thickness of air gap between the heater and the thermocouple has the considerable impact on value of necessary time of heating of a sensitive element for receiving authentic results of measurement;

2) Difference in minimum necessary duration of heating up of the thermocouple for execution of measurements with the minimum error are insignificant, therefore existence of an insulating ceramic cap has no essential impact on result of measurement.

Acknowledgments

This work was supported by the Russian Foundation for Basic Research, project 14-08-00057.

References

1. T. V. Borovkova, V.N. Yeliseyev, and I.I. Lopukhov, Phys. Part. Nuclei, **5**, 3 (2008).
2. N. Zhu, K. Shan, S. Wang, and Y. Sun, Energ. Buildings, **67** (2013).
3. L. Tsikonis, J. Albrektsson, J.Van herle, and D. Favrat, J. Power Sources, **245** (2014).
4. G.V. Kuznetsov and K.M. Mukhammadeev, J. Engineering Thermophysics, **19**, 1 (2010).
5. Y. K. Atroshenko, I.P. Ozerova, P. A. Strizhak, Adv. Mater. Res., **1040** (2014).
6. Y. K. Atroshenko, P.A. Strizhak, O.S. Yashutina, EPJ Web of Conferences **82**, 01061 (2015).
7. G. Beges, M. Rudman, J. Drnovsek, Int. J. Thermophys., 32 (2011).
8. IEC 60584-2. International standard. Thermocouples. Part 2: Tolerances, 1989.
9. A. A. Samarskii, The Theory of Difference Schemes, Marcel Dekker, Inc., USA, 2001.
10. N.B. Vargaftik, Reference Book on Thermophysical Properties of Gases and Liquids, Stars, Moscow [in Russian], 2006.
11. R. Hultgren Selected Values of the Thermodynamic Properties of Binary Alloys, USA, American Society for Metals, 1973.