Sensors & Transducers, Vol. 160, Issue 12, December 2013, pp. 55-61

www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Method of Thermocouples Self Verification on Operation Place

[1] Chang SHU, [2] Orest KOCHAN
[1] School of Economics Management, Northwest University of Politics and Law,
Xi'an, Shaanxi, 710063, China.
[2] Department of Metal Physics, Ivan Franko National University of L'viv,
Universytetska str., 1, Lviv, 79000, Ukraine
E-mail: orestvk@gmail.com

Received: 13 October 2013 /Accepted: 22 November 2013 /Published: 30 December 2013

Abstract: The method of periodic verification in operation condition of the main thermocouple of thermocouple based sensor with controlled profile of temperature field (TBS with CPTP) is proposed in this paper. This periodic verification can be done without dismantling out of sensor from operation place as well as without any working standards. The reference thermocouples of either 1st or 3rd level of hierarchy scheme can be used for verification of TBS with CPTP right after produce. Evaluation of self verification error in this case has shown value of error at either 1 ºC or 1.2 ºC respectively. *Copyright © 2013 IFSA.*

Keywords: Temperature calibrator, Frequent verification.

---

1. Introduction

Thermocouples (TC) are widely used sensors in measuring temperatures above 600 °C. However, they have long been the least reliable and accurate part of measuring channel. Errors of common standardized TC for the last decades have not become smaller. The major disadvantages of TC are:

- The initial deviation of the conversion characteristic (CC) from nominal is quite large. For the most common K-type TC, it reaches 5.5 °C at 600 °C, and 8 °C at 1100 °C [1].
- There is a big drift of CC during long-term operation at high temperatures. For K-type TC it reaches 0.5 °C at 600 °C, and 10°C at 1100 °C for 1000 hours of operation [2, 3];
- A thermoelectric inhomogeneity of TC electrodes acquired during operation time at high temperature is also large. For K-type TC, the error reaches 2 °C at 600 °C and 11 °C at 1100 °C for 1000 hours of operation [4].

The last disadvantage has led to the hasty conclusion about the impossibility of correction errors of TC, which have been in use [6]. However, methods of error correction of such TC have appeared recently. Therefore, let's take a look at the possibilities to improve the accuracy of temperature measurement, using TC

1.1. Analysis of Methods for Improving the Accuracy of Thermocouples

Development of new alloys for TC electrodes has not led to a significant increase in accuracy of TC. Correcting methods can be divided into two groups:

1. The ones, that require stationary profile of the temperature field of measurement object during the operation TC;
2. The ones, that take into account possible change of the temperature field profile along the TC electrodes.

The first group includes a frequent verification of TC in lab, and use of obtained errors as amendments. This method has a significant acquired inhomogeneity. The best methods are:

1. Verification on operation place using reference TC. It has to be inserted into an additional channel of temperature sensor [2];
2. Calibration using temperature calibrator. Calibrator is a hermetical capsule that contains either pure metal or alloy inside with a known temperature of phase transition (melting / solidification). It is located at the hot junction of TC and creates a temperature plateau at the time of the phase transition [5].

Additional increase of accuracy of temperature measurement, while reducing the complexity, is possible by constructing an error model of TC for its individual prognosis during operation process [8]. However, the above mentioned methods require a new verification or calibration during the profile change of the temperature field of the temperature measurement object. Otherwise, an error from acquired thermoelectric inhomogeneity will not lead to the accuracy increase of temperature measurement.

Inhomogeneity of thermoelectrodes leads to an additional error when temperature field changes. It was proposed to provide verification of TC in a few profiles of temperature field [7] for TC error correction in this case. Such verification allows to determine coefficients for individual models of drift of CC of each section of TC. Recognition properties of neural networks are used for decreasing of points of verification.

Substantial increase in accuracy at operation in condition of unstable temperature field provides thermocouple based sensor with controlled profile of temperature field (TBS with CPTF) [8]. In TBS with CPTF the profile of the temperature field along the electrodes of the main thermocouple (MTC) is stabilized by additional control systems. Such systems include additional TC, heaters and multichannel control system. This solution also allows us to set a necessary profile of the temperature field along the electrodes of MTC during the operation. This creates additional possibilities to improve the accuracy of temperature measurement.

The purpose of the article is to develop a method of periodic self-verification MTC of TBS with CPTF on operation place without additional means. This method will enable the use of methods [6, 7] to improve the accuracy of temperature measurements in condition of variable temperature field profile of the measurement object.

2. The Theoretical Basis of the Proposed Method

Let TC electrodes operate in the temperature field, which is described by monotonic dependence. We divide each TC electrode into zones $i = \overline{1, n}$. Electromotive force (EMF) E_k for $k -$ zone can be written as

$$E_k = (e_N + \Delta e_k) \cdot (t_{k+1} - t_k), \tag{1}$$

where e_N, Δe_k are the nominal value of the specific EMF of the given electrode material and its individual deviation for $k -$ area; t_{k+1}, t_k – temperature boundaries of the $k -$ electrode zone.

If the difference $t_{k+1} - t_k$ approaches to zero, total EMF E_Σ of one electrode will be

$$\begin{aligned} E_\Sigma &= \int_0^{t_{rk}} (e_N + \Delta e_k)dt = \int_0^{t_{rk}} e_N dt + \int_0^{t_{rk}} \Delta e_k dt = \\ &= E_{\Sigma N} + \int_0^{t_{rk}} \Delta e_k dt, \end{aligned} \tag{2}$$

where $E_{\Sigma N}$ is the nominal value of EMF, which generates each electrode under affect of given temperature difference $t_{rk} - t_0$. Integral determines the total error of the electrode ΔE_Σ.

During the operation time τ, electrodes change its chemical composition (oxidation, migration) and crystalline structure under the influence of high temperatures. Intensity of changes considerably depends on the operation temperature t_e of each zone [7-9], which means that $\Delta e_k = \Delta e(t_e, \tau)$. According to (2) it is possible to find a total error ΔE_Σ of electrode with certain profile of operation temperature field. [9]

$$\begin{aligned} \Delta E_\Sigma &= \int_0^{t_{rk}} \Delta e_k dt = \int_0^{l} \Delta e(t_e, \tau) \frac{\partial t}{\partial l} dl = \\ &= \Delta e(t_e, \tau) \int_0^{l} \frac{\partial t}{\partial l} dl \end{aligned} \tag{3}$$

From (3) the following conclusions can be derived [9]:

1. If $\partial t / \partial l \to 0$, than $\Delta E_\Sigma \to 0$. Drift $\Delta e_k = \Delta e(t_e, \tau)$ of TC's zones, which are being used at a temperature field without gradient (zones $l_0 \ldots l_3$ and $l_4 \ldots l_7$ of the curve A from the Fig. 1), does not cause errors in the measurement result.
2. If $\Delta e(t_e, \tau) \to 0$, than $\Delta E_\Sigma \to 0$. Drift of zones, which are used at the temperature of cold junctions t_{CJ} (zones $l_0 \ldots l_3$ of curve A on the fig. 1), is absent. It does not cause errors in the measurement result.

3. If $\Delta e_k = \Delta e(t_e, \tau)$ and $\Delta e \approx k \cdot t_e$ (drift is proportional to the operation temperature [2, 3]), than $0 < \Delta E_\Sigma < \Delta E_\Sigma^{MAX}$. Total drift of the zones, that are used in the gradient of the temperature field (zones $l_3 \cdots l_4$ of the curve A on the Fig. 1), has an average value. This total drift is formed by zones at different temperatures - from minimum to maximum.

4. If $\Delta e_k = \Delta e(t_e, \tau)$ and $\Delta e \approx k \cdot t_e$, then the maximum value of electrodes drift ΔE_Σ^{MAX} can be determined in the profile of temperature field of the curve B (Fig. 1). Then the $l_5 \cdots l_6$ zones, which create EMF, previously have been used at the maximum temperature (temperature of the hot junction t_{HJ}). That is why they have a maximum deviation of the specific EMF Δe_k from their initial value before operation, which means that $\Delta e_k \to \max$.

5. If $\Delta e_k = \Delta e(t_e, \tau)$ and $\Delta e \approx k \cdot t_e$, then $\Delta e_k \to 0$ when moving the electrodes to the temperature field of the curve C (Fig. 1). Zones $l_0 \cdots l_3$, which have not been operated at the high temperature generate EMF. These zones were at the temperature of cold junctions t_{CJ} . This refers to paragraph 2. Therefore, the result of measuring the temperature in this case is free from drift of thermocouple CC.

The last conclusion can serve as a basis for the method of self verification of TC on operation place [10].

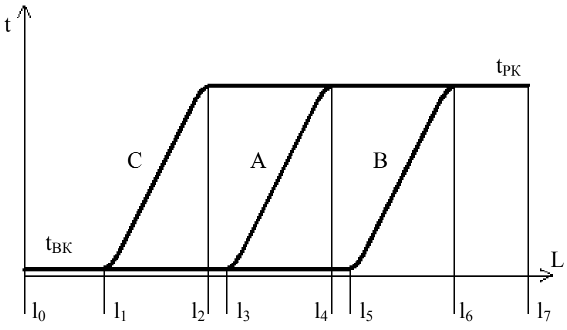

Fig. 1. Profiles of the temperature field along the thermocouple electrodes.

3. Realization of the Method of Self Verification of Thermocouples

The realization of the proposed method of TBS with CPTF self verification on operation place involves finding the difference between EMF E_A in the temperature field of the curve A and EMF in the temperature field of the curve C (Fig. 1). EMF E_A includes drift error ΔE_A of zones $l_3 \cdots l_4$ in the operation temperature field. EMF E_C is free from drift error. Zones $l_1 \cdots l_2$ are used at low temperature of cold junctions t_{CJ} . Their drift is relatively small.

TBS with CPTF provides control of temperature field profile. Therefore, the proposed method of self verification can be implemented. Conditions of this verification method are:

1. Constancy of hot junction t_{HJ} and cold junctions t_{CJ} temperatures during verification period.
2. Sufficient "shift" of temperature field gradient ($l_2 \ldots l_3 > 0$).

To improve the accuracy of temperature measurement, it is necessary to eliminate the error of initial deviation of individual CC of $l_1 \cdots l_2$ zones from nominal one. To achieve this, TBS with CPTF has to be checked at manufacture using reference TC. At the same time, zones $l_1 \cdots l_2$ (profile C of temperature field, Fig. 1) should generate an EMF. The same zones will generate an EMF during self verification. Therefore, we can eliminate the influence of error of the initial deviation of CC from initial one on the result of verification.

A process of TBS with CPTF's metrological service with self verification is illustrated on Fig. 2. At the manufacture of TBS with CPTF, the verification is done in profile of the temperature field using reference TC (Fig. 2a). This takes into account individual deviations of CC of $l_0 \cdots l_1$ zones from nominal one. According to (3), the following expression can be written

$$\begin{aligned} \Delta E_\Sigma = \int_{l0}^{l1} \Delta e_1(t_e,\tau)\frac{\partial t}{\partial l}dl + \int_{l1}^{l2} \Delta e_2(t_e,\tau)\frac{\partial t}{\partial l}dl + \\ + \int_{l2}^{l3} \Delta e_3(t_e,\tau)\frac{\partial t}{\partial l}dl + \int_{l3}^{l4} \Delta e_4(t_e,\tau)\frac{\partial t}{\partial l}dl, \end{aligned} \qquad (4)$$

where $l_0 \cdots l_4$ are the MTC's zones according to fig. 2; $\Delta e_1(t_e, \tau) \ldots \Delta e_4(t_e, \tau)$ – individual deviations of the specific EMF of MTC areas according to Fig. 2.

At the beginning of operation (during the initial verification) $\tau = \tau 0$. According to paragraph 1, if $\partial t / \partial l \to 0$, then $\Delta E_\Sigma \to 0$. Therefore, following expression can be written

$$\Delta e_2(t_e, \tau 0) = \Delta e_3(t_e, \tau 0) = \Delta e_4(t_e, \tau 0) = 0 \qquad (5)$$

and convert (4)

$$\Delta E_\Sigma^{FT} = \int_{l0}^{l1} \Delta e_1(t_e, \tau 0)\frac{\partial t}{\partial l}dl , \qquad (6)$$

where ΔE_{Σ}^{FT} is the result of the initial verification (individual deviation of CC of $l_0 \cdots l_1$ zones from the initial on

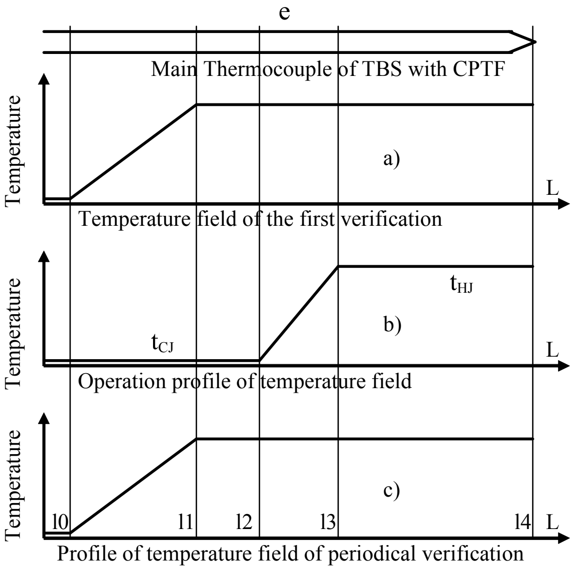

Fig. 2. Process of metrological service of TBS with CPTF during the work cycle.

Further the TBS with CPTF operates in the profile of the temperature field shown on Fig. 2 (b). Suppose the operation time is $\tau = \tau 1$. At the same time, the zones $l_2 \cdots l_4$ drift. In contradiction to (5), $\Delta e_3(t_e,\tau 1) \neq \Delta e_4(t_e,\tau 1) \neq 0$. The zones $l_0 \cdots l_2$ are located at the temperature t_{CJ} and do not drift. Then, $\Delta e_1(t_e,\tau 1) = \Delta e_2(t_e,\tau 1) = 0$. However, for zones $l_3 \cdots l_4$ the gradient $\partial t/\partial l \to 0$. Therefore, $E_{l3...l4} \to 0$ and drift of the zones $l_3 \cdots l_4$ does not affect the error of the total EMF. For this case, the following can be written similar to (6)

$$\Delta E_{\Sigma}^{E} = \int_{l2}^{l3} \Delta e_3(t_e,\tau 1)\frac{\partial t}{\partial l}dl, \qquad (7)$$

where ΔE_{Σ}^{E} is the error of individual deviation of CC of zones $l_2 \cdots l_3$ from initial one during the operation time, for time $\tau = \tau 1$ (including the time drift due to the effect of high operation temperature).

Periodic verification of TBS with CPTF is done under the following conditions:

1. Temperature of the hot junction of MTC t_{HJ} has not changed for some time;
2. We can expect the absence of changes of temperature t_{HJ} during 20…30 minutes.

To provide periodic verification of TBS with CPTF, profile of the temperature field has to be set according to Fig. 2c). This profile should be the same as the profile of temperature field of the initial verification (Fig. 2 (a)). In this case,

$$\Delta e_3(t_e,\tau 1) \neq \Delta e_4(t_e,\tau 1) \neq 0 .$$

However, for zones $l_1 \cdots l_4$: $\partial t \partial l \to 0$. That is why, if $E_{l1...l4} \to 0$, then the zones $l_1 \cdots l_4$ do not affect on the total EMF of MTC. Therefore, the result of periodic verification ΔE_{Σ}^{PT} can be derived as

$$\Delta E_{\Sigma}^{PT} = \int_{l0}^{l1} \Delta e_1(t_e,\tau 1)\frac{\partial t}{\partial l}dl \qquad (8)$$

We can assume in the first approximation that $\Delta e_1(t_e,\tau 1) = \Delta e_1(t_e,\tau 0)$, because the zones $l_0 \cdots l_1$ were at high temperature for a short period of time (just for a time of self verification), and the (8) completely corresponds to (6).

The error of the proposed method of self verification will be evaluated in camera ready.

4. Estimation of the Error of Self verification

Analysis of (4), (6)… (8) allows to identify error sources of self verification of TBS with CPTF. During the first verification (just after produce) the main error sources are following reasons:

1. Reference thermocouple error of the primary verification Δ_R. This error depends from the status of the reference thermocouple. Error range is 0.3 – 0.6 °C [11].
2. Measurement of e.m.f. error of reference thermocouple Δ_R^E. For high-quality measurement systems its magnitude doesn't exceed 0.4 °C. So $\Delta_R^E \leq 0.4°C$ [12].
3. Cold junction temperature correction error of the reference thermocouple Δ_R^{CJ}. Typical value of this error for high-quality is $\Delta_R^{CJ} \leq 0.1°C$ [13].
4. Temperature determination after e.m.f. of the reference thermocouple error Δ_R^{LIN} (linearization and errors correction). For high-quality microcontroller-based measurement systems its magnitude $\Delta_R^{LIN} \leq 0.1°C$ [12].
5. E.m.f. measurement error Δ_X^E of the produced thermocouple. For type K thermocouples $\Delta_X^E \leq 0.1°C$ [12].
6. Cold junction temperature correction error of the produced thermocouple Δ_X^{CJ}. For high-quality measurement systems $\Delta_X^{CJ} \leq 0.1°C$ [13].

7. Temperature determination after e.m.f. of the produced thermocouple error Δ_X^{LIN} (linearization and errors correction). For high-quality microcontroller-based measurement systems its magnitude $\Delta_X^{LIN} \le 0.1\,°C$ [12].

8. Error due to inadequacy of a cold junction temperature of the reference thermocouple and the produced on

$\Delta_X^{DT} \le 0{,}1\,°C$ [13] if a nickel temperature leveling device is used.

9. Error caused by a switch Δ^C. For high-quality measurement systems $\Delta^C \le 0{,}1\,°C$ for reference type S thermocouples and $\Delta^C \le 0{,}03\,°C$ for type K thermocouples [12].

Thus total error of the primary verification Δ_Σ^{FT} of a TBS with CPTF can be defined as (9):

$$\Delta_\Sigma^{FT} = \sqrt{\Delta_{R^2} + \Delta_R^{E^2} + \Delta_R^{CJ^2} + \Delta_R^{LIN^2} + \Delta_X^{E^2} + \Delta_X^{CJ^2} + \Delta_X^{LIN^2} + \Delta_X^{DT^2} + \Delta_R^{C^2} + \Delta_X^{C^2}} \tag{9}$$

Putting to the formula (9) corresponding errors mentioned above, we get $\Delta_\Sigma^{FT} \le 0.6...0.8\,°C$ (exact value depends on which status of the reference thermocouple is used)

The main error sources during the periodical testing are following:

1. Reference device error that is used for periodical verification Δ_R^{PT}. In other words zones $l_0 \cdots l_1$ of the MTC for proposed self verification method. This error analysis is given below.

2. E.m.f. measurement error Δ_X^E of a thermocouple that is verified. For high-quality measurement systems $\Delta_X^E \le 0.1\,°C$ [12].

3. Cold junction temperature correction error of a thermocouple that is verified. For high-quality measurement systems $\Delta_X^{CJ} \le 0.1\,°C$ [13].

4. Temperature determination after e.m.f. of a thermocouple that is verified Δ_X^{LIN} (linearization and errors correction). For high-quality microcontroller-based measurement systems $\Delta_X^{LIN} \le 0.1\,°C$ [12].

5. Error due to hot junction temperature change of a thermocouple that is verified Δ_X^{HJDT}. This error depends from chosen instant of a self verification. It can't be estimated precisely. It is necessary to measure temperature of an object before and after self verification for its estimation. A tolerant difference may be estimated using tolerant range of a self verification error. It is necessary to repeat self verification one more time if this difference exceeds tolerance limits. Analysis of temperature changes in big power plant furnaces showed that magnitude of this error is limited by $\Delta_X^{HJDT} \le 0.4\,°C$.

6. Error caused by a switch Δ_X^C. For high-quality measurement systems $\Delta_X^C \le 0.03\,°C$ for type K thermocouples [12].

7. Error caused by TBS with CPTF temperature field profile nonideality Δ_X^F. This error is estimated below.

A periodic verification reference device is the zones $l_0 \cdots l_1$ of MTC. Deviations of their CC from the nominal one are fixed in the first verification. Thus the error Δ_R^{PT} will be defined by a zone $l_0 \cdots l_1$ CC drift during operating time. Drift Δ_X^{ED} doesn't exceed 24.5 °C for operating time $\tau_E = 8000$ hours at operating temperature $T_E = 800\,°C$ for type K thermocouples [3].

Let's suppose: (i) time of verification doesn't exceed $\tau_{ST} = 0.5$ an hour (ii) self verification is provided once a week. During the one year operating time total time of zones $l_0 \cdots l_1$ of MTC operation will not exceed $\tau_{ER} = 26$ hour. For type K thermocouples drift of the first 100 hour of operation equals to approximately half of the drift one year operation drift [3]. That's why it is reasonable to prepare MTC before the primary verification. This preparation consists of operating of MTC in temperature field that "cover" future profile of the primary verification's temperature field during 100…150 hours. Then Δ_R^{PT} will correspond to approximately 50 % of the maximum type K thermocouple drift during the time $\tau_{ER} = 26$ hour, divided by $\tau_E = 8000$ hour. Thus $\Delta_R^{PT} = (\tau_{ST} \cdot \tau_{ER} \cdot \Delta_X^{ED}) / \tau_E \le 0.04\,°C$.

Error due to nonideal TBS with CPTF profile of temperature field Δ_X^F is defined by the profile of temperature field set Δ_X^{FS} (relatively to temperature field of TBS with CPTF during the primary verification) and error due to control Δ_X^{FC}. The error Δ_X^{FS} is defined by the control systems of TBS with CPTF additional thermocouples CC drift during operating time (their initial deviations of CC from nominal are taken into account in the primary verification of the TC). This error for used type K additional thermocouples $\Delta_X^{FS} \le 24.5\ °C$ [3]. The error due to control Δ_X^{FC} doesn't exceed 1.2°C [14]. So, in this case Δ_X^F doesn't exceed $\Delta_X^F = \sqrt{\Delta_X^{FS^2} + \Delta_X^{FC^2}} \approx 25\ °C$. However Δ_X^F doesn't affect the verification error directly. It calls another error. The MTC total e.m.f. involves the e.m.f. generated by $l_1 \cdots l_4$ zones in primary as well as periodical verification. Just the individual deviations of the MTC CC from nominal can affect on the verification error of the zones $l_1 \cdots l_2$. They are taken into account at the primary verification. The zones $l_1 \cdots l_2$ are not operated in high temperature. Hence their error is neglectible small. Effect of $l_2 \cdots l_4$ zones is much greater. Their individual deviations of CC from nominal are taken into account at the primary verification. But they are operated at high temperature. That's why the zones $l_2 \cdots l_4$ CC drift affects on periodical verification. Equivalent effect Δ_X^{EQ} on the total MTC e.m.f. equals to $\Delta_X^{EQ} = \Delta_X^{FS} \cdot \Delta_X^F / T_E \le 0.75\ °C$ if temperature field deviates on $\Delta_X^F \le 25\ °C$.

Thus additional error Δ_X^{PT} that appears at periodical verification of the MTC approximately equals to

$$\Delta_X^{PT} = \sqrt{\Delta_R^{PT^2} + \Delta_X^{E^2} + \Delta_X^{CJ^2} + \Delta_X^{LIN^2} + \Delta_X^{HJDT^2} + \Delta_X^{C^2} + \Delta_X^{EQ^2}} \approx 0.8\ °C \tag{10}$$

The total error of a periodical verification Δ_Σ^{PT} equals to summation of the primary verification error Δ_Σ^{FT} and the additional error of a periodical error Δ_X^{PT} . If the first rank reference thermocouple is used for primary verification

$$\Delta_\Sigma^{PT} = \sqrt{\left(\Delta_\Sigma^{FT}\right)^2 + \left(\Delta_\Sigma^{PT}\right)^2} \le 1°C \tag{11}$$

The total error of primary verification Δ_Σ^{PT} , if the third rank reference thermocouple is used, equals to

$$\Delta_\Sigma^{PT} = \sqrt{\left(\Delta_\Sigma^{FT}\right)^2 + \left(\Delta_\Sigma^{PT}\right)^2} \le 1.2\ °C \tag{12}$$

5. Conclusions

The proposed method of the main thermocouple of TBS with CPTF verification can be considered as quite prospective. Its advantages are: (i) possibility of the periodical TBS with CPTF verification on operation place without replacement of a sensor; (ii) periodical verification doesn't require reference thermocouple or any other reference temperature sensor; (iii) the periodical verification error doesn't exceed 1.2 °C. Thus it is reasonable to generate algorithm for design of such sensors for various use.

References

[1]. International standard Thermocouples: IEC 60584-2. Geneve, 1982.

[2]. L. Kortvelyessy, Thermoelement Praxis, *Vulkan-Verlag*, Essen, 1981.

[3]. N. Rogelberg, A. Nuzhnov, G. Pokrovskaya, et. al., The stability of the chromel-alumel thermocouples' thermoelectric power at temperatures up to 1200 C. Investigation of alloys for thermocouples: in *Proceedings of the Giprotsvetmetobrabotka*, XXIX. Metallurgy, Moscow, 1967, pp. 54-65.

[4]. Sloneker K. C., Thermocouple inhomogeneity, *Ceramic Industry,* Vol. 159, Issue 4, April 2009.

[5]. Alf Hundves, Henz G. Buschfort, Self calibrating temperature sensing probe and probe – indicator combination, *United State Patent* No. 3.499.340.73-1, G01 -15/00.

[6]. A. Sachenko, V. Kochan, V. Turchenko, V. Golovko, Y. Savitsky, T. Laopoulos, Method of the Training Set Formation for Neural Network Predicting Drift of Data Acquisition Device, *Ukrainian Patent* No. 50380, IPC 7 G06F15/18, Filled 04 Jan 2000, Issued 15 November 2002.

[7]. N. Vasylkiv, Increasing of the accuracy of temperature measurement using thermocouples in operating process, Abstract of Ph. D. Dissertation, *Lviv National University 'Lviv Polytechnic',* 2010.

[8]. O. Kochan, R. Kochan, O. Bojko, M. Chyrka, Temperature Measurement System Based on Thermocouple With Controlled Temperature Field, in *Proceedings of the IEEE International Workshop on Intelligent Data Acquisition and Advancing Computing Systems (IDAACS'2007).* Dortmund, Germany, September 6 – 8, 2007, pp. 47-51.

[9]. O. Kochan, R. Kochan, V. Yaskilka, N. Vasylkiv, Estimation of the maximum error of inhomogeneous thermocouples, *Transactions of the Ternopil State National University,* 2007, 1, pp. 122-129.

[10]. O. Kochan, Method of the main thermocouple's error correction on operation place, *Ukraine Patent* a201213268, IPC 7 G01K, Filled 21.11.2012.

[11]. State system for ensuring the uniformity of measurements. Thermoelectric transducers. Verification procedure, State Standard 8.338-2002, *Minsk Printhouse of Standards*, 2003, 23 p.

[12]. V. Golovko, L. Grandinetti, T. Laopoulos, A. Sachenko, V. Kochan, V. Turchenko, V. Tymchyshyn, Approach of an Intelligent Sensing Instrumentation Structure Development, in

Proceedings of the IEEE International Workshop on Intelligent Signal Processing (WISP'99), Budapest, Hungary, 4-7 September, 1999, pp. 336-341.

[13]. I. Bilousov, Precision increase of multichannel measurement devices with thermocouples, Abstract of Ph. D. Dissertation, Lviv, 1991, 20 p.

[14]. N. Vasyl'kiv, O. Kochan, R. Kochan, M. Chyrka, The Control System of the Profile of Temperature Field, in *Proceedings of the 5-th IEEE International Workshop (IDAACS'09),* Rende (Cosenza), Italy, September 21-23, 2009, pp. 201-206.