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Information-measuring System to Study the Thermocouple with Controlled Temperature Field

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Error due to inhomogeneity is the main problem of thermocouples (TCs), e.g., during the operation of a type K TC, this error can reach 11-30 °C. Thus, metrological reliability of TCs is threatened by this error because there is a high risk of exceeding the permissible error when the temperature distribution along the TC legs changes. Such a large error, in turn, can threaten a proper operation or even safety of a measured object. A TC with controlled temperature field was proposed to cope with this error. An information-measuring system to perform proper measurements, measurement data acquisition and collection to construct mathematical models is proposed. Its property is high diurnal stability of ±(0.0025+0,002(X/X_{MAX}–1) %. The requirements for the information-measuring system and its structure are considered in this paper. In particular, one of the key problems of such a sensor is how stable is its own temperature field under the influence of the temperature field of a measured object. The experimental studies were carried out using the developed system. They showed that the coefficient of penetration of the temperature field of the measured object is about 0.04. This allows decreasing error due to inhomogeneity by about 10-20 times.

Keywords: Temperature, temperature measurement, thermocouple, thermocouple with controlled temperature field, error due to inhomogeneity.

1. INTRODUCTION

Measurements play a very important role in scientific progress. That is why there are many types of sensors [1], [2]. New ideas in sensors and sensor technologies as well as in measuring methods and techniques appear at a fast rate [3]-[7].

Metrology is a branch of science whose primary interest is measurements. It plays an important role in the world economy [8]-[10]. Recently it has gained new areas [11]-[13]. One of the modern trends is the use of artificial intelligence to improve the accuracy of measurements [3], [13]-[15].

There are many sources of errors in measuring systems, in particular, power supply [16], measuring equipment [17], interference [18], etc. However, usually the sensor is the main source of errors [19].

The temperature is one of the most frequently measured physical quantities. The thermocouple (TC) is the most widely used temperature sensor. In accurate temperature measurement systems based on TC the error of a measuring channel is almost completely determined by the error of their TC [19], [20]. This is due to the relatively large initial scattering of a TC conversion characteristic (CC) [1], and significant drift of their CCs during TC operation. The drift is associated with the degradation processes in TC legs under the influence of operating temperatures and time [21]. The effect of these factors leads to a change in both the chemical composition and crystalline structure of TC legs. This, in turn, leads to a change in TC CC. A number of methods have been developed to correct the error of TCs caused by the drift of their CC. One of the most effective methods among them is based on the construction of a mathematical model of the TC error due to drift using a neural network [19]. The results of a periodic determination of the TC error by either a standard TC [21] or a temperature fixed point cell [22] are used to train the neural network.

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However, the rate of degradation in TC legs is a function of their operating temperature [21]. Therefore, the CCs of those sections of the TC legs which are operated at high temperatures change with respect to their individual operating temperatures. When changing the temperature field along the TC legs, their sections change their developed thermo-emf, since the temperature difference at their ends changes. Therefore, the thermo-emf developed by a TC becomes dependent not only on the temperature difference between the measuring and reference junctions, but also on the temperature field, that is on the temperature distribution along the TC legs [20], [23], [24]. This is the way how the error due to acquired thermoelectric inhomogeneity of TC legs appears [23], [24]. The maximum value of the error due to acquired thermoelectric inhomogeneity of TC legs is considerable. This error may reach 11 °C according to the estimation given in [20], it is up to 30 °C according to the estimation carried out in [24], and in some cases this error reaches even over 150 °C [25] when measuring temperatures within the range of 800-1000 °C.

Error due to inhomogeneity has been known since 1906 [26] but recent studies show that it is still a problem [23], [25], [27]. Since then, it has been considered to be the main source of the TC error [23], [26]. The presence of acquired thermoelectric inhomogeneity of TC legs considerably worsens the correction of the error due to drift of the TC CC [20], therefore, the correction of the error due to drift of TC CC without the correction of the error due to acquired inhomogeneity becomes unreasonable.

2. METHODS OF REDUCING ERROR DUE TO ACQUIRED INHOMOGENEITY

A number of methods have been developed to mitigate the error due to acquired inhomogeneity. These methods were analyzed in [28]. It was shown in [28] that:

1. There is a method of calculating the error due to acquired inhomogeneity for the temperature field of operation using the error determined in a calibration, based on the results of previous studies of the error due to drift of the TC CC. It does not take into account the individual nature of the drift and the effect of the rate of drift in particular operating conditions;
2. The improved version of the previous method based on the results of periodic determination of the TC error is using either a reference TC [21] or a temperature fixed point cell [22]. The method makes it possible to increase the accuracy of the correction of the error due to acquired inhomogeneity;
3. A criterion to estimate the accuracy of the correction of the error due to acquired inhomogeneity was proposed in [29], [30]. It made possible a reliable estimation of a TC error in any temperature field using the error obtained in a calibration.

However, the abovementioned methods improve the accuracy of temperature measurements only in case of short-time and rare changes of the temperature field along the TC legs. That is when changes of the temperature field do not cause the change of main trends of degradation of sections of the TC legs.

A new type of TCs, the thermocouple with controlled temperature field (TCTF) was proposed in [14] in order to radically reduce the effect of acquired inhomogeneity on measurement results. A schematic diagram of the temperature measurement system based on the TCTF is given in Fig.1. Its key component is the main TC (MTC) connected to the measurement channel (MMC) of the measuring and control subsystem M&CS. The temperature field along the MTC legs is stabilized by the *n* auxiliary temperature control subsystems. Each such subsystem consists of an auxiliary thermocouple, heater H1 ... Hn and temperature regulator. There are *n* such subsystems shown in Fig.1. as the inputs TC1 ... TCn and outputs CC1 ... n of the M&CS.

The TCTF creates its own temperature field along the legs of the MTC using the auxiliary temperature control subsystem during operation [14]. Therefore, the error of the MTC due to its thermoelectric inhomogeneity cannot manifest itself [14]. However, the implementation of such a TCTF requires fundamental theoretical and experimental studies because there are several key problems in the TCTF such as: (i) control of temperature field; (ii) the error of method caused by the heat flux from the heaters to the measuring junction of the MTC; (iii) influence of the changes in an external temperature field on the temperature distribution along the legs of the MTC created by the heaters. Methods to control the temperature field were proposed in [31], [32] (to solve the problem mentioned in point (i) from the previous sentence. The error of method was considered in [33] (the key problem (ii) from the list above). The purpose of this article is to develop a special information-measuring system (IMS) for the experimental studies of the prototype of the TCTF proposed [14] and study the influence of the changes in an external temperature field on the temperature distribution along the legs of the MTC created by the heaters.

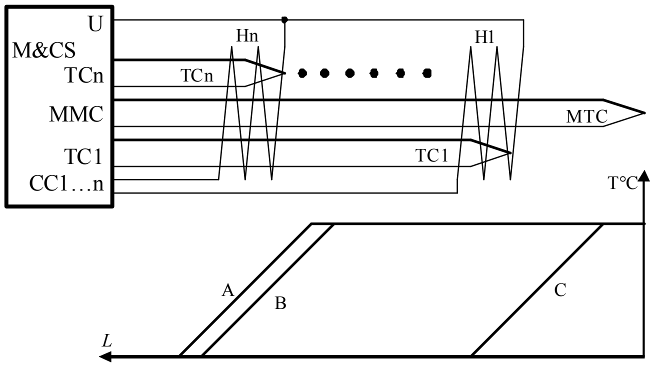

Fig.1. A schematic diagram of the temperature measurement system based on the TCTF.

3. THE PROTOTYPE OF THE TCTF

The drawing of the proposed TCTF is given in Fig.2. The temperature of an object is measured by the MTC 10. Its measuring junction is placed in the tip of the thermowell 9, and the reference junction is in the box 1. The thermocouples TC1 (position 3) ... TCn (position 9), that measure the temperatures of all sections, are placed into the main thermowell 7. They are insulated with ceramic beads.

The main thermowell 7 is covered with refractory enamel. The sections of the heater 4 are wound on it. Current to the heaters is supplied by wires located in the ceramic beads 2. The heat insulation 6 reduces the heat loses of heaters to the environment. Metal tubes 5 constitute an external TCTF housing.

The TC1 ... TCn and H1 ... Nn are located along the MTC in such a way, that it is possible to fully control the temperature distribution along its legs. However, H1 ... Hn should not influence the temperature of the MTC measuring junction. Therefore, the MTC's measuring junction is placed into the tip of the thermowell 9, which should be far enough to dissipate the thermal flux from the heaters [33]. In the prototype this distance is 15 cm [33].

There are multiple functions of the box 1:

1. It is a thermal flattener to level the temperatures of the reference junctions of the MTC and the remaining thermocouples TC1 (position 3) ... TCn (position 9).
2. It is a container for the temperature sensor of the reference junctions for all the TCs. This prevents the use of extension cables and thus eliminates their error.
3. It contains terminals for connection to the cable of the reference junctions for all the TCs. The cable transmits their thermo-emfs to the measuring and control subsystem M&CS.
4. It also contains the connection terminals of the heaters H1 ... Hn to connect them to the corresponding control channels CC1 ... n.

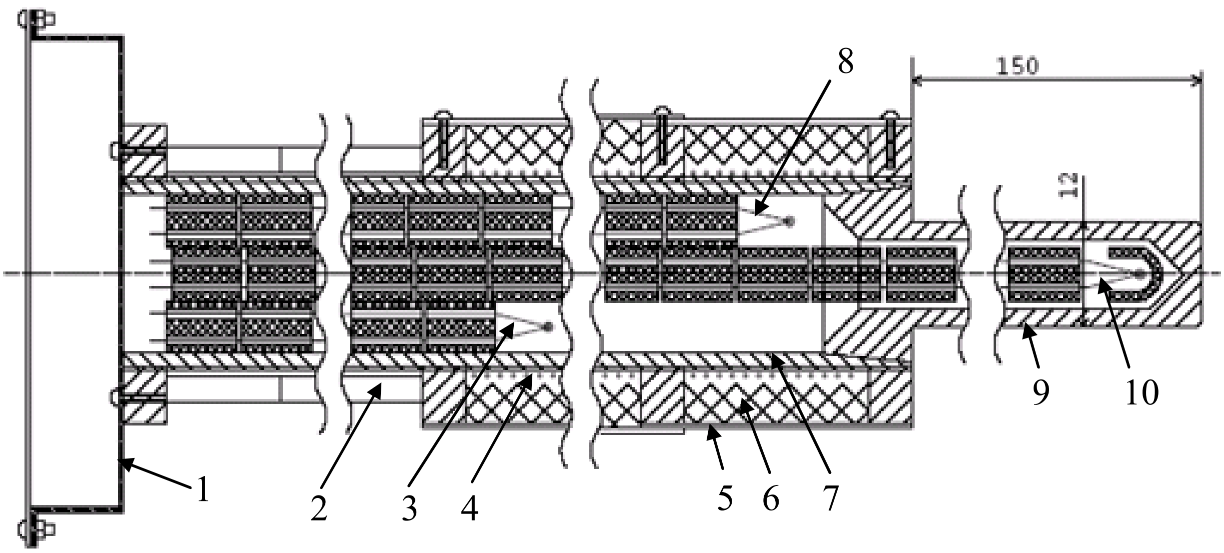

Fig.2. The drawing of the proposed TCTF.

Such a design of the TCTF prototype enables the purposeful control of the temperature field along the MTC legs. In particular, it is possible to stabilize the temperature field along the MTC legs (for example, according to curve A in Fig.1.). Changes of the ambient temperature fields within the limits B and C (see Fig.1.) will not influence the temperature field along the MTC legs.

4. REQUIREMENTS FOR THE SPECIAL IMS

The main goal of the IMS is to provide conditions that simulate the operation of the TCTF. It is supposed to study its performance and specific errors.

The TCTF requires a measuring and control subsystem M&CS. Its number of voltage measurement channels is determined by:

1. zero setting requires one channel;
2. calibration requires one channel;
3. the MTC requires one channel;
4. the auxiliary thermocouples TC1 ... TCn require nine channels;
5. two channels to measure the voltages across the reference resistor and the resistance thermometer. The voltage divider circuit with the four-wire method to measure the resistance of the resistance thermometer and the reference resistor [1] is used to ensure the required accuracy of correction of the reference junction temperature for the TCs.

After summing up the abovementioned requirements one receives 14 channels in total. Type K TCs are used in the prototype [33]. Their sensitivity is about 40 μV/°C [1]. The range of measured voltage is determined by the maximum thermo-emf of 50 mV. It is necessary to have a margin of 20 ... 30 % to avoid the phenomenon of limiting the normal mode noise, otherwise noise immunity of the measuring system will be considerably reduced.

It is necessary to have a significant margin for sensitivity to study the effect of various external factors on the TCTF. Therefore, in the developed IMS, the measuring channels have a sensitivity of 1 μV, which corresponds to a temperature of about 0.025 °C for the chosen type K TCs.

The maximum permissible error of the measuring channels should be less than the expected change in TC thermo-emf under the impact of influencing factors, therefore, it should be commensurable with the system's sensitivity. However, in this case the maximum permissible error will be 0.002 ... 0.0025 %.

The measuring system should be placed as close to the furnace that is a part of the IMS as possible. This requirement is due to the need for the maximum reduction of wires, which connect the TCs to the measuring system. Otherwise, the normal mode noise will rise. The residual noise will increase random errors of the measuring system. This error is the most dangerous when studying the effects of the influencing factors. On the other hand, the location of the measuring system near the furnace leads to significant changes in the temperature of its operation. Thus, the effect of the additional temperature error on measurements rises. In this case, it is difficult to meet the abovementioned maximum permissible error.

However, virtually all measurements in the study are relative ones. That is, the studies are limited to measuring changes of the thermo-emfs developed by the MTC under the effect of the influencing factors. In this case, the absolute error of measurement is not very important. Stability of the measuring instrumentation during the experiment is more important. Therefore, it was decided to specify two parameters that determine the error of the experimental studies, such as the limit of permissible error and permissible instability for the time of one experiment, which is for 9 hours.

5. THE STRUCTURE OF THE DEVELOPED IMS

To solve the abovementioned problems during the construction of the IMS, the following technical solutions are used:

1. The microconverter ADUC-834 [34] was used as a core of the measuring system. It contains a 24-bit sigma delta analog-to-digital converter (ADC);
2. An automatic correction of the additive and multiplicative errors is used to reduce the ADC error.
3. The reed switches with auxiliary thermal flatteners are used to reduce the additive error of the measuring channel;
4. The source of calibration voltage is based on the precision stabilizer AD780 [35] and the thin film resistive voltage divider 301HP5 [36] to reduce the multiplicative error of the measurement channel;
5. A shielded power supply (primary and secondary windings of the power transformer are wound up in different pins of a U-shaped core with a metal screen between the pins) is used to reduce the common mode noise and the galvanic insulation of interfaces using optocouplers.

The structure of the developed IMS is given in Fig.3. The core element of the IMS is a tubular furnace. It consists of a furnace heater H and a system for stabilizing the furnace temperature. This system includes the thermocouple TC, the circuit to correct the temperature of its reference junction TRJ, the analog-to-digital converter ADC, the microcontroller MC, and the thyristor TYR. The TCTF is placed into the furnace. The TCTF consists of the main thermocouple MTC, nine zones of temperature stabilization along the MTC legs (they include heaters H1 ... H9 and thermocouples TC1 ... TC9), and the circuit to correct their temperatures of the reference junctions TRJ.

The IMS also includes a measuring and control subsystem M&CS and a personal computer IBM PC. The measuring and control subsystem M&CS consists of an input switchboard, a source of calibration voltage Uref, a microconverter ADUC-834 [34], a pulse width modulators PWM (based on another microcontroller), and power switches. The ADUC-834 includes the 24-bit sigma-delta ADC and a microcontroller compatible with the i51 series. This microcontroller carries out basic data processing in the M&CS. All units of the IMS are wired by a local network based on the modified interface RS-232 [37]. Control by all units of the IMS is performed using the personal computer IBM PC. The IBM PC also collects the measurement data. A picture of the developed IMS is shown in Fig.4.

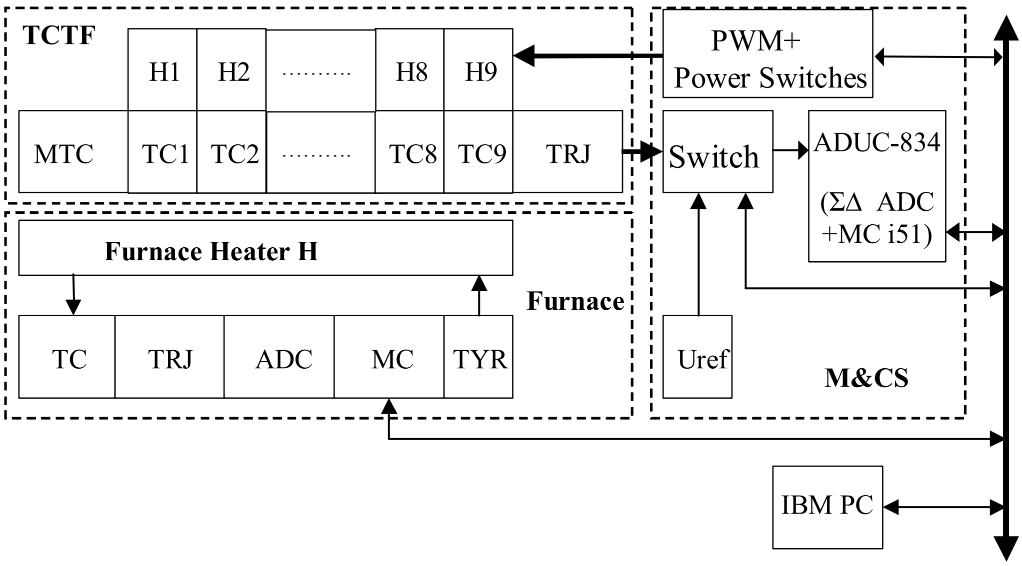

Fig.3. The structure of the developed IMS.

We use the Ethernet network twisted pair to wire the TCs and heaters. It reduces the pulse interference and normal mode noise. Experimental studies have shown that in connection with the D9 socket, such a cable has parasitic thermo-emf of less than 1 μV even under the influence of the thermal flux from the furnace. These measures make it possible to ensure the metrological parameters of the M&CS given in Table 1. As it can be seen from the table, the requirements for the M&CS are met.

The microcontroller, that is a part of the ADUC-834, uses the measured temperatures of the zones of the TCTF to compute control actions which are implemented by the microcontroller that is a part of the PWM. It should be noted that TCTF is a multi-zone object. Therefore, the widespread laws of regulation (in particular, PI, PID) do not provide the required accuracy in maintaining the temperature field along the MTC legs because of significant effects of thermal fluxes between zones. In this case the controllers of certain zones lose their stability (that is fall into the self-oscillation mode). That is why a control method that computes the required power changes for all zones [31] simultaneously was proposed. Then these power changes are applied by the PWM over a period of time sufficient for thermal transition in the TCTF zones to finish. Then the procedure of correction of the of heaters' powers is repeated. The process of regulation converges to the iterative approximation of the heaters' power to the value required to maintain a preset temperature field.

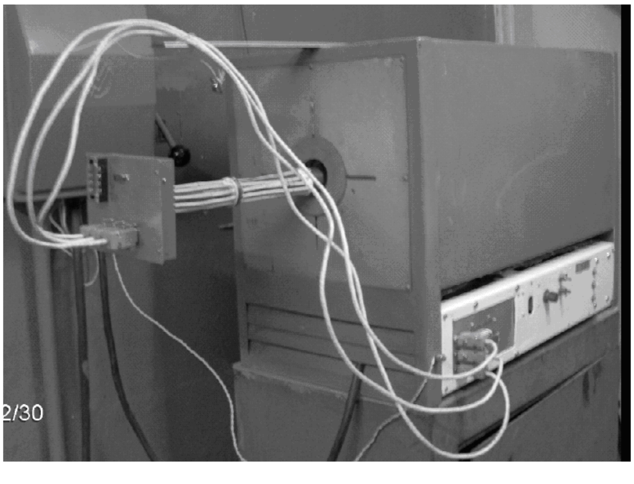

Fig.4. Picture of the developed IMS.

The advantages of this method are: (i) absence of self-oscillations and (ii) simplicity. Self-oscillations of small amplitude may appear due to the error of the measuring channel. However, they develop a very small error of 3 ... 4 μV. This error appears due to inhomogeneity of the MTC induced by an unstable temperature field. This instability of the temperature field is due to the error of control. The implementation of the method is solution of the system of n linear equations (in this particular case n = 9).

The disadvantage of the method is the long process of iterative approximation of the temperatures of all zones to the preset values. As it is shown in [31], it takes six iterations to achieve deviations in all zones within the permissible limits from the preset temperature field. Each iteration takes up to one hour. However, in this study this disadvantage is not significant.

Table 1. Technical parameters of the M&CS.

No	Parameter	Value
1.	Number of channels	16
2.	Measuring range	80 mV
3.	Resolution	1 μV
4.	bound of permissible relative error	±(0.05+0.005(X/Xmax-1)) %
5.	Diurnal instability	±(0.0025+0.002(X/Xmax-1)) %
6.	Time of a single measurement	1 s
7.	Normal mode rejection ratio	70 dB
8.	Common mode rejection ratio	140 dB

6. PROCESSING THE EXPERIMENTAL RESULTS

As it was mentioned above, the developed IMS is intended to study the changes in the conversion characteristics under the influence of various factors. Therefore, it is specially designed for relative measurements. There is no need to use standard means in such measurements. The measurement results are formed as deviations of the thermo-emfs developed by the MTC and other TCs. Therefore, the experimental data processing is aimed at obtaining high accuracy of these relative changes. The developed software for the IMS includes the following modules to achieve the aim:

1. Censoring the measuring sample. It is performed always. An algorithm for censoring a sample of eight measurements is used to reduce the normal mode noise. It consists of the following procedures: (i) finding the mean of the results of eight measurements; (ii) the rejection of two results with the maximum positive and negative deviations from the mean; and (iii) finding the mean of the remaining six measuring results. This algorithm virtually eliminates pulse interference as well as significantly reduces random and normal mode noises.

2. Zero setting. In addition, the average values of zero level in the last three measurements are compared. If the difference between them exceeds 2 μV, all values are rejected and the zero setting is repeated. The short-circuit of the ADC input is carried out by a separate switch channel. The switch is based on the double reed relay with an additional thermal flattener. Its parasitic thermo-emf does not exceed 0.5 μV. The number of measurements in zero setting is doubled to reduce noise.

3. Calibration. It is performed using the reference voltage source (see point 4 of chapter 5). Preliminary experimental studies of the multiplicative error of calibration have shown

that it does not exceed 0.015 %. The instability of the calibration source during 9 hours does not exceed 0.0015 %. In addition, the average values of the measurement results of the calibration voltage in the last three measurement cycles are compared. If the difference between them exceeds 2 μV, all values are rejected and the calibration is repeated.

4. As it was mentioned above, the developed IMS is designed to study changes of thermo-emfs under the influence of various factors. Thus, all the series of experimental data begin with a zero value. The paper [38] showed that classical least squares method does not work well in such cases. Therefore, a method was proposed that ensures the equality of sum of residuals to zero for a regression equation passing through the origin of the Cartesian coordinate system for adequate fitting curve to data [38].

5. The developed methods for experimental data processing were implemented in LabVIEW. This makes possible: (i) digital and graphical indication of the experimental raw data in real time; (ii) digital and graphical indication of the processed data in real time; and (iii) recording these data into files for further storage.

7. STUDYING THE INFLUENCE OF AN EXTERNAL TEMPERATURE FIELD ON THE TEMPERATURE DISTRIBUTION ALONG THE MTC LEGS

The main errors of TCTF that need to be experimentally studied using the developed IMS are as follows:

1. The error due to the influence of the thermal flux from the first heater H1 on the temperature of the measuring junction MTC. This error is the error of method for the TCTF. It was shown that this error does not exceed 0.4 °C in case of the proper design of the TCTF [33].

2. The error due to changes in the external temperature field on the temperature distribution along the MTC legs. This error appears due to a non-ideal design of the heaters H1...Hn. This error causes a residual error due to inhomogeneity.

Let us consider the influence of changes of the external temperature field on the temperature distribution along the MTC legs. In general, there are three possible modes of operation for each subsystem of temperature control:

1. The subsystem cannot supply sufficient heat to a TCTF zone due to insufficient power of a heater H_i. In this case, the power of this heater has been 100 % for a long time, however, the temperature of the zone remains lower than the preset.

2. The subsystem operates in a normal mode. In this case, power of each heater for a long time has been within the limits $0 < P_i < 100\%$, and the temperature of the zones remains close to the preset one $T_i \approx T_{izad}$.

3. The subsystem cannot make the temperature of a zone lower. In this case power of this heater has been zero for a long time, however, the temperature of the zone remains higher than the preset one $T_i > T_{izad}$.

It is impossible to stabilize the temperature field profile along the MTC legs by the means of a subsystem of temperature control in the first and third modes. These modes in the TCTF are abnormal. They must be detected by the program of operation of the control subsystem. It has to report about the occurrence of such modes to an operator or higher hierarchical level of the system. In these modes the error due to acquired inhomogeneity of the MTC legs appears. However, this error will be less than in the case of absence of temperature control subsystems (that is, when using a conventional TC). The measuring error in such modes is not considered in this paper.

However, even in case of normal operation of the temperature control subsystem, changes in the external temperature field can somewhat affect the temperature field along the MTC legs. This effect appears due to non-ideal design of the TCTF. Actually, it determines the manifestation of the residual error due to inhomogeneity of the MTC legs. Therefore, the estimation of this effect is necessary. The main difficulty of such an estimation is that in the mode of normal operation of a control subsystem, temperatures of all zones are approximately equal to the preset ones. Therefore, the temperature measurements by TC1 ... TC9 do not carry the information about the effect of the external temperature field. This effect is maximum between heaters where there is no TC to measure temperature at this particular place. It is impossible to study this effect even using a furnace with controlled temperature field and a system for measuring the profile of the external temperature field.

On the other hand, we do not need to know the exact dependence of the internal temperature field on the external one. The effect of the external temperature field on the internal one causes only a residual error due to inhomogeneity of the MTC. It is obvious that small changes in the external temperature field induce small changes in the internal one. Small changes in the temperature field of MTC have little effect on the residual error due to inhomogeneity. Thus, it is necessary to estimate the maximum deviation of the internal temperature field from the preset one under relatively large changes in the external temperature field.

It is suggested to artificially create a change in the external temperature field by turning off one of the heaters. The created temperature difference will induce a thermal flux which penetrates to the MTC legs. There is a temperature sensor, a zone TC, whose corresponding heater is turned off, in the center of the area of the maximum penetration. The difference between the measured temperature with the heater on and off simulates the influence of the external temperature field on the internal one. In this way one can approximately estimate the "coefficient of penetration" of the external temperature field through the "gap", which equals the width of one zone.

The experimental technique is as follows:

1. Establish a preset temperature in the furnace and keep the prototype of the TCTF with the heaters off until the end of the furnace thermal transition.

2. Measure the temperatures T_i^A of all zones of the TCTF prototype by the TC1...TC9.

3. Turn on all the zone heaters of the TCTF at full power and wait until the end of thermal transition.

4. Measure the temperatures of all zones of the TCTF prototype T_i^B by the TC1 ... TC9.
5. Turn off one of the heaters of the TCTF prototype and wait until the end of cooling transition. Preliminary studies of the prototype presented in Fig.2. show that it is reasonable to turn off the seventh heater (the count starts from the reference junction). Because of asymmetry of the temperature field developed by the heaters, the seventh heater gives the maximum temperature change.
6. Measure the temperatures of all zones of the TCTF prototype T_i^C by TC1 ... TC9.

The maximum additional heating ΔT_i^B from the full power operation of all zone heaters can be determined as the difference between the temperatures of corresponding zones when all heaters are in on mode (see points 3 and 4 from the list above) and when all heaters are off (see points 1 and 2 from the list above) $\Delta T_i^B = T_i^B - T_i^A$. The plot ΔT_i^B vs zone number is given in Fig.5. (the top curve of blue color). Additional heating ΔT_i^C from the full power operation of all but the 7-th zone heaters (the seventh heater is off) can be determined as the difference between the temperatures of corresponding zones when all but the 7-th heaters are on (see points 5 and 6 from the list above) and when all heaters are off (see points 1 and 2 from the list above) $\Delta T_i^C = T_i^C - T_i^A$. The plot ΔT_i^C vs zone number is also given in Fig.5. (the middle curve of orange color). These two curves characterize the "penetration" of the external temperature to the MTC legs through the "gap" that equals the width of the seventh heater. The difference between these temperatures (the lowest curve in Fig.5. of black color) corresponds to the simulated influence of the external temperature field on the internal one. The value of the above mentioned "coefficient of penetration" can be estimated as the ratio of the maximum value of the difference curve to the maximum value of the change of the temperature field ΔT_i^B. In this particular case we are interested in determining the "coefficient of penetration" for the 7-th zone. As it can be seen from Fig.5., the maximum value of the difference curve is in zone 7 and it is 5 °C. The maximum value of the change of the temperature field ΔT_i^B is in zone 7 and it is 28 °C. Thus, the approximate value of the experimentally determined "coefficient of penetration" equals $K_{EXP} = 5°C / 28°C \approx 0{,}2$. It should be noted that the obtained value corresponds to the "gap" whose width equals the width of one heater. In the prototype given in Fig.2., the width of the "gap" (i.e., the distance between the end of a heater and the beginning of the successive one) is about 5 times smaller than the width of the heater.

Although the dependence of temperature change on width of the "gap" is non-linear, to estimate the error due to inhomogeneity, it can be assumed that the "coefficient of penetration" is proportional to the "gap" width. Therefore, the value of the "coefficient of penetration" should be considered 5 times smaller during operation, that is $K_{REAL} \le 0{,}04$. This value is acceptable in order to decrease the error due to inhomogeneity of the MTC in 10 ... 20 times.

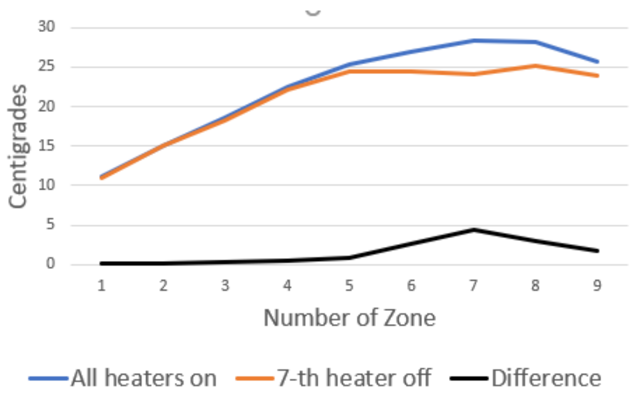

Fig.5. Changes in external temperature vs the temperature distribution along the MTC legs.

8. CONCLUSIONS

The main contribution to the net error of measurement comes from the sensor.

The thermocouple has many errors but the main source of its error is thermoelectric inhomogeneity of its legs. It has been a problem for more than a century [26]. Recent studies show the possible ways of coping with this problem [14], [27].

The existing methods for TC error correction have low efficiency because of thermoelectric inhomogeneity. They work well in a stable temperature field but are not very effective in case of changes in temperature distribution along the TC legs. The sensor proposed in [14] is intended to maintain a stable temperature distribution along the TC legs and expand the area of usage of the methods for TC error correction.

There is a constructed prototype of the TCTF proposed in [14].

The IMS to study the TCTF prototype, considered in this article, allows carrying out experimental studies of the specific errors of the proposed TCTF. The study of the influence of changes in the external temperature field on the temperature distribution along the MTC legs shows that this effect is insignificant and one can significantly decrease error due to inhomogeneity of the MTC legs by approximately 10-20 times.

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