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MUNDARIJA | ОГЛАВЛЕНИЕ | TABLE OF CONTENTS

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Algorithm of functioning of intellectual information-measuring system

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Abstract. The article is devoted to the development and research of the algorithm of functioning of the intellectual information-measuring system (IIMS), designed to improve the accuracy of the technological process of manufacturing mineral wool boards. Experimental studies of thermal insulating materials with the use of IIMS and approaches to the monitoring of mode parameters at various stages of the technological line are considered. Methods and algorithms allowing to realize in the system intellectual functions of selection of technological process parameters, and also to adapt and correct the controlled parameters at influence of destabilizing factors that promotes increase of quality of let out production on 10-15%, as results of researches show are described

Thus, this paper represents a significant contribution to the field of IIS development for industrial applications, as it proposes efficient algorithms for tolerance control and process correction, which in turn contributes to improving the quality of manufactured products.

Keywords: Intelligent information-measuring system (IIMS); tolerance control; thermophysical properties of materials; nondestructive testing; mathematical modeling; simulation modeling in MATLAB; metrological analysis; knowledge base; procedural rules; microcontroller; correction of technological parameters; improving accuracy and efficiency of measurements; control algorithm; systematic and random errors.

Introduction

The developed method of increase of accuracy of tolerance control of thermal conductivity and production of mineral wool boards as a result of monitoring of parameters of raw materials, mode parameters of technological process of production and technological equipment, correction of controlled and accounting of uncontrolled parameters of technological process of their production, is realized in the created IIS, providing relative error of measurement of thermal conductivity of mineral wool not more than 4%, that corresponds to permissible values of accuracy of information.

Technology Advancement: With the continuous development of artificial intelligence, machine learning and big data technologies, there is an opportunity to create more efficient and smarter information and measurement systems.

Market demands: Industry, healthcare, science, and others need more accurate, faster, and more reliable information and measurement systems to make critical decisions [5,6].

Process Optimisation: MIS are capable of collecting, processing and analysing large amounts of data in real time, making them an important tool for optimising processes and improving operational efficiency.

Automation and smart solutions: The algorithms used in intelligent information and measurement systems enable automated solutions for monitoring, diagnostics and process control, reducing human error and improving accuracy.

Big Data: In today's world, a huge amount of data is collected. The algorithms used in IIS help extract valuable insights from this data, which is key to making informed decisions [7,8].

Security and reliability: With the rise of cyber threats and the need to protect data, it becomes important to build intelligent systems that can detect and respond to threats in real time.

All these factors highlight the relevance of the topic "Algorithm for Intelligent Information and Measurement System Functioning" in today's society, where the ever-increasing amount of data requires smart and efficient approaches to its analysis, processing and use [9,10].

Materials and methods

We propose a block diagram of the algorithm for realization of tolerance control of mode parameters, presented in Figure 1, using the developed method of increasing the accuracy of tolerance control [1,2].

Thermophysical measurements on determination of Investigated material (IM) parameters P_λ with IIMS start with identification of IM state U_{IO}. The user enters a priori information about the IM: information about the permissible power of thermal influence q, destabilizing factors (DF) D, and defines the correspondence $S \in S_m$.

Measurement procedure (MP) 1 is performed, which consists in thermal influence on the IM and taking a test thermogram. The test thermogram is used to determine the primary measurement information about the IM, influencing DFs and to form a measurement situation.

To complete the task, Measurement procedure 1 needs to query the Knowledge base for information on the heat measurement mode characteristics for a particular IM type, such as q and K (where K denotes the amplifier gains of the IIMS), and determine if they are within acceptable values.

After the process of identifying the state of the IM has been carried out, the parameters of this equipment are determined by the intelligent information measurement system

IIS implements intellectual functions for the selection of mode parameters of the process of manufacturing mineral wool slabs with a given thermal conductivity, has the ability to implement the interaction of the IM with the system, namely the ability to adjust the indicators of controlled parameters under the influence of destabilizing factors, which allows to improve the quality of mineral wool, as shown by the results of experimental studies, by 10-15%.

IIS has the ability to solve weakly formalized problems, in particular, the tasks that require the availability of the technological process of manufacturing mineral wool slabs implementation of the decision-making algorithm depending on the specific situation, which is characterized by dynamism and uncertainty.

The results of monitoring of mode parameters of the technological process of mineral wool boards production are used for decision-making in determining the permissible mode parameters in order to improve the accuracy of the technological process on the basis of the developed procedural rules for the knowledge base of the IIS (Table 1):

Table 1. Procedural rules of the IIS knowledge base

IF T_{os}	∈	T_{os} (18.1800-20.7900)°C,	SO	(OP) T_{os} ∈ (OP) $T_{os\ extra}$;
IF V_{os}	∈	V_{os} (48.4800-59.4000)%	SO	(OP) V_{os} ∈ (OP) $V_{os\ extra}$
IF C	∈	C (70,7000-80,0800)%	SO	(OP) C ∈ (OP) C_{extra}
IF W_{mfm}	∈	W_{mfm} (20,2000-29,7000)%	SO	(OP) W_{mfm} ∈ (OP) $W_{mfm\ extra}$
IF C_{bc}	∈	C_{bc} (2.0200-4.9500)%	SO	(OP) C_{bc} ∈ (OP) $C_{bc\ extra}$
IF C_{ma}	∈	C_{ma} (4,0400-9,9000)%	SO	(OP) C_{ma} ∈ (OP) $C_{ma\ extra}$
IF S_c	∈	S_c (6060-6930)rpm	SO	(OP) S_c ∈ (OP) $S_{c\ extra}$
IF P_{ht}	∈	P_{ht} (1212-1485)°C	SO	(OP) P_{ht} ∈ (OP) $P_{ht\ extra}$

First, the obtained numbers are compared with the real permissible values for each controlled mode parameter (all this is displayed on the IIS display). Then the algorithm of monitoring and tolerance control of mode parameters is realized. The last mode parameter is the heat treatment level P_{ht}. If $P_{ht} \in P_{ht\ extra}$, the control of mode parameters is completed (indication on the display "mode parameters are normal"). If not, the parameter is corrected in the heat treatment chamber and the entire material is sent for processing again. Control of temperature (*T*) in the contact zone of the measuring probe with the material under study (indication on the display of the IIS). Then $T(x_n,\tau_i)$ is compared with ε_d, where ε_d is the distance from the temperature probe to the heater, is the current time, ε_d is the set temperature threshold value. If $T > \varepsilon_d$, the control of *T* continues. If $T > \varepsilon_d$, the probe is placed on the material under test. Then thermal influence on the material under study is carried out with the help of a linear heater when heating pulses of the set power are applied to it (the heating process is indicated on the IIS display). At the same time the thermogram is registered and recorded in the microcontroller memory according to the data of temperature sensors in the measuring zone (in the area of contact of the measuring probe with the material under study). Then the heating pulses applied to the material under test are switched off. Controlled information parameters of temperatures $T_n(x_i,\tau_i)$ *and* $T_m(x_i,\tau_i)$ are recorded in the memory.

Fig. 1. Block diagram of the algorithm of realization of tolerance control of mode parameters and initial materials when determining the thermal conductivity of materials

Calculation of parameters of thermophysical properties of materials - thermal conductivity coefficients (λ) and thermal diffusivity (σ) (indication of λ and a on the IIS display) is carried out by temperature-time characteristics $T_n(x_i,\tau_i)$, $T_m(x_i,\tau_i)$. The relative error (δ) of determination of λ and a is calculated (indication of δ_λ δ_σ values is carried out on the IIS display). After that, the IIS user enters the density value (ρ) for the material under study. The heat capacity (c) is calculated (indication on the IIS display). The mathematical expectation (M) is calculated (indication on the display of the IIS). RMS error (σ) is calculated (indication on the IIS display). And at the final stage, the absolute and relative error limits λ and a ($\Delta_{\max}\lambda_j, \Delta_{\max}a_j$) are calculated (indication on the IIS display). All information about the tolerance values for each parameter and calculation formulas for finding various indicators are stored in the IIS knowledge base. Thus, as a result of using the IIS the monitoring and control of the main mode parameters affecting the final values of thermal conductivity and quality of the obtained materials is carried out, the measurement of the main thermophysical parameters and the calculation of absolute and relative errors of measurements are carried out. The output parameters determining the accuracy of λ determination include: loss of accuracy and efficiency, measurement error in thermal conductivity control. Consequently, ensuring the improvement of quality and production of mineral wool boards with thermal conductivity corresponding to the regulatory requirements on the basis of increasing the accuracy of the technological process, allows to control the mode parameters at the stages of the technological line of production of mineral wool boards using the developed intelligent information-measuring system and the algorithm of its operation. Experimental studies of heat-insulating materials with the use of IIS have been carried out. Figure 2 shows thermograms of heat-insulating materials with different values of λ determined with the help of IIS. The time τ to reach the steady-state thermal regime in the area of contact of the IIS probe with the material under study depends significantly on λ and is the longer, the less λ of the material. Consequently, when working with investigated materials of this class it is inexpedient to set one fixed time in IIS, for example, for ripor $\tau_{et.r} = 140s$ (it corresponds to the supply of thermal pulses).

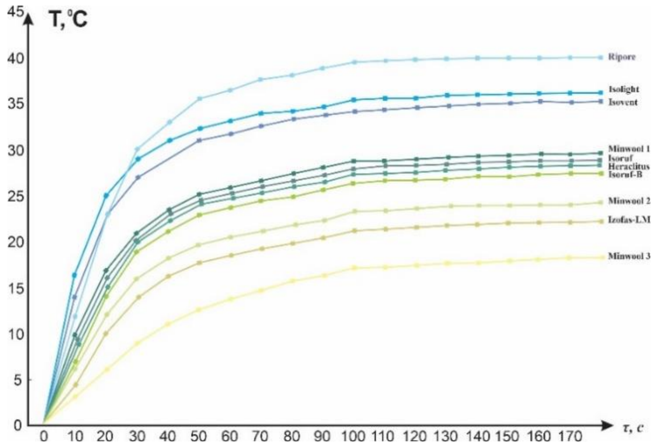

Fig. 2 Thermograms of investigated materials

The measurement error will be used as I_{ai}, and the measurement time λ will be used as I_{ri}. Functional dependencies of these losses on τ_{er} must take into account the applied method of controlling λ of materials and the influence of destabilizing factors, i.e.

$$I_{ai} = f_{ai}(\tau_{er}, M, O, D_f);\ I_{ri} = f_{ri}(\tau_{er}, M),$$

where D_f is the set of destabilizing factors, O is the set of investigated materials, M is the set λ of control methods applied in the IIS, which are entered in the knowledge base of the IIS. For each method and investigated material there is some value of τ_{er}, at which the criterion, comprehensively taking into account the loss of accuracy and operability, is minimal. To determine the optimal value of $\tau_{er}*$ we introduce an optimality criterion that takes into account losses of accuracy and operability in a complex way, namely

$$J(\tau_{er}, M, O) = [C_1 I_{ai}(\tau_{er} M, O, D_f) + C_2 I_{ri}(\tau_{er}, M] \to \min_{\tau_{er}, M},$$

where C_1, C_2 are weight coefficients.

The variation of the criterion $J = (\tau_{er}, M, O)$ when $C_1 = C_2 = 1$ for the loss, I_{ai} and I_{ri} dependencies, is shown in Fig. 3, the optimal time to reach the steady-state thermal regime in this case is equal to 105 s.

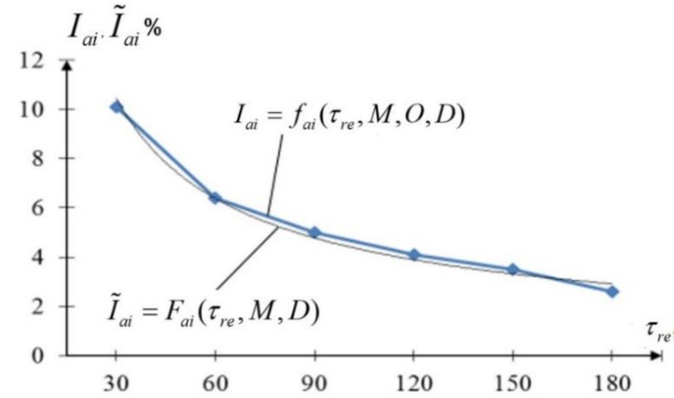

Fig. 3 Graph of dependencies of $I_{ai} = f_{ai}(\tau_{re}, M, O, D)$ and approximating function $\tilde{I}_{ai} = F_{ai}(\tau_{re}) = 10.459\tau_{re}^{-0.713}$

Results

Table 2 summarizes the results of experimental studies of mineral wool and other thermal insulation materials, as well as the loss of accuracy and efficiency of product quality assessment in the production of mineral wool boards using the developed analytical model [3,4].

Table 2. Results of an experimental study of mineral wool

Objects under study	$\lambda_{rv}, Vt/m \cdot K$	$\lambda_m, Vt/m \cdot K$	δ, %	I_{ai}, %	I_{ri}, %
Ripore	0,028	0,0282	0,7142	7,0123	18,2341
Heraclitus	0,035	0,0348	0,5714	6,0101	16,2121
Isolight	0,032	0,0323	0,9375	2,3111	11,1111
Isoruf	0,034	0,0337	0,8824	2,2420	11,2200
Isoruf-B	0,035	0,0347	0,8571	2,7131	12,1100
Izofas-LM	0,039	0,0394	1,0256	5,4221	15,2340

Graphical representation of these functions for the considered method and the investigated material - PMM, are shown, respectively, in Fig. 4 and Fig. 5 for averaged values of λ and under destabilizing factors typical for laboratory test conditions. Similar dependences take place for other materials and methods when determining their thermal conductivity in laboratory conditions.

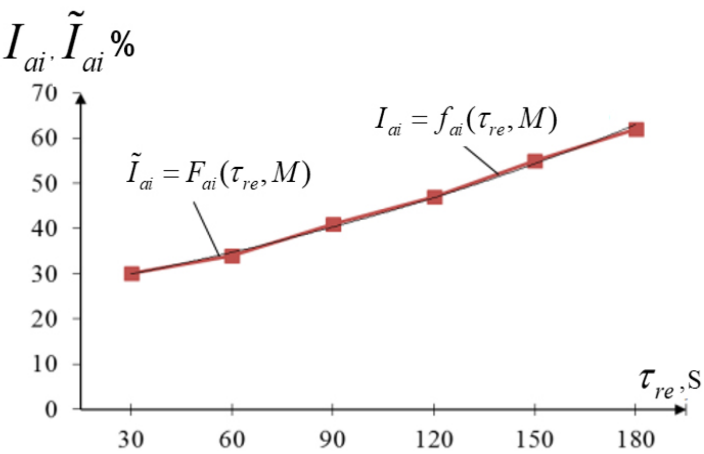

Fig. 4 Graph of dependencies of $I_{ai} = f_{ai}(\tau_{re}, M)$ and approximating function $\tilde{I}_{ai} = F_{ai}(\tau_{re}, M) = 25.791e^{0,1488\tau_{re}}$

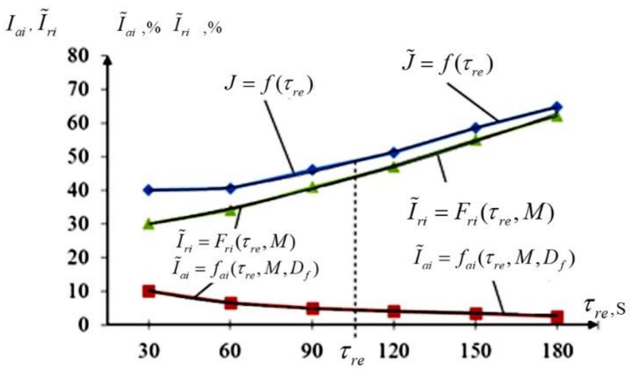

Fig. 5 Graph of dependencies of $J = f(\tau_{re}, O_{RMM})$ and approximating function

$\tilde{I}_{ai} = f_{ai}(\tau_{re}, M, D_f) = -(0.1255)\tau_{re}^3 + 1.6236\tau_{re}^2 - 7.4652\tau_{re} + 16.007;$

$\tilde{I}_{ri} = F_{ri}(\tau_{re}, M) = -(0.1019)\tau_{re}^3 + (1.4087 \cdot 10^{-4})\tau_{re}^2 - 0.9392\tau_{re} + 27,667;$

$\tilde{J} = F(\tau_{re}) = -(0.2273)\tau_{re}^3 + 3.0323\tau_{re}^2 - 6.5261\tau_{re} + 43.673.$

Results of experimental studies of mineral wool and other thermal insulation materials, as well as improvement of accuracy (ΔPT) and efficiency (ΔPop) of product quality assessment in the production process mineral wool boards using the developed method of tolerance control accuracy improvement are given in Table 3.

The accuracy gain (ΔPT) is based on the fact that before the method was applied, the loss of accuracy of the PT was 10% on average. ΔPop is based on the fact that without the accuracy improvement method, the tolerance control was 50%.

Table 3. Identified data on the accuracy and effectiveness of mineral fibres in experimental studies

Type of materials under investigation	$\lambda_{rv}, Vt/m \cdot K$	$\lambda_m, Vt/m \cdot K$	δ, %	$\Delta_{I_{ai}}$, %	$\Delta_{I_{ri}}$, %
Ripore	0,028	0,0283	1,0714	2,9877	31,7659
Heraclitus	0,035	0,0345	0,9375	3,9899	33,7879
Isolight	0,032	0,0323	1,5625	7,6889	38,8889
Isovent	0,032	0,0315	2,0588	3,1122	33,1123
Isoruf	0,034	0,0347	1,8181	7,7580	38,7800
Minwool 1	0,033	0,0324	1,6231	1,9010	38,9100
Minwool 2	0,037	0,0364	2,5000	1,6234	36,9895
Minwool 3	0,04	0,0410	1,7647	2,5123	34,9674
Isoruf-B	0,035	0,0346	1,7647	7,2869	37,8900
Izofas-LM	0,039	0,0397	1,7949	4,5779	34,7660

Conclusion

Application of the method of tolerance control accuracy increase and realizing its AIIS allows to increase operability (average increase of operability ΔPop was 36%) and accuracy (average increase of ΔPT = 6%) of nondestructive control of thermophysical properties of thermal insulation materials.

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