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MUNDARIJA | ОГЛАВЛЕНИЕ | TABLE OF CONTENTS

Muxtarov Farrux Muhammadovich, TARMOQ TRAFIGI ANOMALIYALARINI IDENTIFIKATSIYA QILISHNING STATIK USULI	4-7
Daliyev Baxtiyor Sirojiddinovich, Abelning umumlashgan integral tenglamasini yechish uchun Sobolev fazosida optimal kvadratur formulalar	8-14
Umarov Shuxratjon Azizjonovich, KRIPTOBARDOSHLI KRIPTOGRAFIK TIZIMLAR VA ULARNING KLASSIFIKATSIYASI	15-21
Zulunov Ravshanbek Mamatovich, PYTHONDA NEYRON TARMOQNI QURISH VA BASHORAT QILISH	22-26
Djalilov Mamatisa Latibdjanovich, IKKI QATLAMLI NOELASTIK PLASTINKANING KO'NDALANG TEBRANISHI UMUMIY TENGLAMASINI TAHLIL QILISH	27-30
Erkin Uljaev, Azizjon Abdulkhamidov, Utkirjon Ubaydullayev, A Convolutional Neural Network For Classification Cotton Boll Opening Degree	31-36
Seytov Aybek Jumabayevich, Xusanov Azimjon Mamadaliyevich, Magistral kanallarda suv resurslarini boshqarish jarayonlarini modellashtirish algoritmini ishlab chiqish	37-43
Abdullayev Temurbek Marufjonovich, Algorithm of functioning of intellectual information-measuring system	44-49
Odinakhon Sadikovna Rayimjanova, Usmonali Umarovich Iskandarov, Reaserch of highly sensitive deformation semiconductor sensors based on AFV	50-53
S.S.Radjabov, G.R.Mirzayeva, A.O.Tillavoldiyev, J.A.Allayorov, BARG TASVIRI BO'YICHA MADANIY O'SIMLIKLARNING FITOSANITAR HOLATINI ANIQLASH ALGORITMLARI	54-59
Эргашев Отабек Мирзапулатович, Интеллектуальный оптоэлектронный прибор для учета и контроля расходом воды в открытых каналах	60-65
Xomidov Xushnudbek Rapiqjon o'g'li, Nurmatov Sardorbek Xasanboy o'g'li, Yo'ldashev Bilol Iqboljon o'g'li, O'lmasov Farrux Yorqinjon o'g'li, Konus setkali chang tozalovchi qurilma uchun chang namunalarning dispers tarkibi tahlili	66-69
Akhundjanov Umidjon Yunus ugli, VERIFICATION OF STATIC SIGNATURE USING CONVOLUTIONAL NEURAL NETWORK	70-74
Лазарева Марина Викторовна, Горовик Александр Альфредович, Цифровизация и цифровой менеджмент в современном управлении	75-81
D.X.Tojimatov, KIBERTAHDIDLARNI OLDINI OLIHDA KIBERRAZVEDKA AMALIYOTI VA UNING USTUVOR VAZIFALARI	82-85
Muxtarov Farrux Muhammadovich, Rasulov Akbarali Maxamatovich, Ibroximov Nodirbek Ikromjonovich, Kompyuter eksperimenti orqali kam atomli mis klasterlarining geometrik tuzilishini o'rganish	86-89
Umurzakova Dilnoza Maxamadjanovna, BOSHQARISH QONUNLARINI ADAPTATSIYALASH ALGORITMLARINI ISHLAB CHIQLASH	90-94
Muxamedieva Dildora Kabilovna, Muxtarov Farrux Muhammadovich, Sotvoldiev Dilshodbek Marifjonovich, JAMOAT TRANSPORTI MARSHRUTLARINI QURISH INTELLEKTUAL ALGORITMLARI	95-103
Нурдинова Разияхон Абдихаликовна, Перспективы применения элементов с аномальными фотовольтаическими напряжениями	104-108
Bozarov Baxromjon Pخomovich, UCH O'LCHOVLI FAZODAGI SFERADAANIQLANGAN FUNKSIYALARNI TAQRIBIY INTEGRALLASH UCHUN OPTIMAL KUBATUR FORMULALAR	109-113
Улжаев Эркин, Худойбердиев Элёр Фахриддин угли, Нарзуллаев Шохрух Нурали угли, РАЗРАБОТКА КОНСТРУКЦИИ И ФУНКЦИОНАЛЬНОЙ СХЕМЫ ПОЛУЦИЛИНДРИЧЕСКОГО ЁМКОСТНОГО ПОТОЧНОГО ВЛАГОМЕРА	114-122
Mamirov Uktam Farkhodovich, Buronov Bunyod Mamurjon ugli, ALGORITHMS FOR FORMATION OF CONTROL EFFECTS IN CONDITIONS OF UNOBSERVABLE DISTURBANCES	123-127
Sharibayev Nosirjon Yusubjanovich, Jabborov Anvar Mansurjonovich, YURAK-QON TOMIR KASALLIKLARI DIAGNOSTIKASI UCHUN TEXNOLOGIYALAR, ALGORITMLAR VA VOSITALAR	128-136
Marina Lazareva, Estimating development time and complexity of programs	137-141
Asrayev Muhammadmullo, ONLINE HANDWRITING RECOGNITION	142-146
Norinov Muhammadyunus Usibjonovich, SPEKTR ZONALI TASVIRLARGA INTELLEKTUAL ISHLOV BERISH USULLARI TAHLILI	147-152
Xudoynazarov Umidjon Umarjon o'g'li, PARAMETRLI ALGEBRAGA ASOSLANGAN EL-GAMAL SHIFRLASH ALGORITMLARINI GOMOMORFIK XUSUSIYATINI TADQIQ ETISH	153-157
D.M.Okhunov, M.Okhunov, THE ERA OF THE DIGITAL ECONOMY IS AN ERA OF NEW OPPORTUNITIES AND PROSPECTS FOR BUSINESS DEVELOPMENT BASED ON CROWDSOURCING TECHNOLOGIES	158-165

MUNDARIJA | ОГЛАВЛЕНИЕ | TABLE OF CONTENTS

Солиев Бахромжон Набиджонович, Путеводитель по построению веб-API на Django - Шаг за шагом с Django REST framework — от моделей до проверки работоспособности	166-171
Sevinov Jasur Usmonovich, Boborayimov Okhunjon Khushmurod ogli, ALGORITHMS FOR SYNTHESIS OF ADAPTIVE CONTROL SYSTEMS WITH IMPLICIT REFERENCE MODELS BASED ON THE SPEED GRADIENT METHOD	172-176
Mamatov Narzullo Solidjonovich, Jalelova Malika Moyatdin qizi, Tojiboyeva Shaxzoda Xoldorjon qizi, Samijonov Boymirzo Narzullo o'g'li, SUN'IY YO'LDOSHDAN OLINGAN TASVIRDAGI DALA MAYDONI CHEGARALARINI ANIQLASH USULLARI	177-181
Обухов Вадим Анатольевич, Криптография на основе эллиптических кривых (ECC)	182-188
Turdimatov Mamirjon Mirzayevich, Sadirova Xursanoy Xusanboy qizi, AXBOROTNI HIMOYALASHDA CHETLAB O'TISHNING MUMKIN BO'LGAN EHTIMOLLIK XOLATINI BAHOLASH USULLARI	189-193
Musayev Xurshid Sharifjonovich, TRIKOTAJ MAHSULOTLARIDA NUQSONLI TO'QIMALARNING ANIQLASHNING MATEMATIK MODELI VA UNING ALGORITMLARI	194-196
Kodirov Ahkhmadkhon, Umarov Abdumukhtar, Rozaliyev Abdumalikjon, ANALYSIS OF FACIAL RECOGNITION ALGORITHMS IN THE PYTHON PROGRAMMING LANGUAGE	197-205
Suyumov Jorabek Yunusalievich, METHODOLOGICAL PROBLEMS OF QUALIMETRY IN CONDUCT OF PEDAGOGICAL EXPERIMENT-EXAMINATION	206-211
Хаджаев Саидакбар Исмоил угли, АКТУАЛЬНОСТЬ ПРОБЛЕМЫ ЗАЩИТЫ ИНФОРМАЦИОННЫХ СИСТЕМ МАЛОГО И СРЕДНЕГО БИЗНЕСА ОТ КИБЕРАТАК	212-217
M.M.Khalilov, Effect of Heat Treatment on the Photosensitivity of Polycrystalline PbTe Films AND PbS	218-221
Тажибаев Илхом Бахтиёрвич, ПОЛНОСТЬЮ ВОЛОКОННЫЙ СЕНСОР, ОСНОВАННЫЙ НА КОНСТРУКЦИИ ИЗ МАЛОМОДОВОГО ВОЛОКОННОГО СМЕЩЕНИЯ С КАСКАДНЫМ СОЕДИНЕНИЕМ ВОЛОКОННОЙ РЕШЕТКИ С БОЛЬШИМ ИНТЕРВАЛОМ, ИСПОЛЬЗУЕТСЯ ДЛЯ ОПРЕДЕЛЕНИЯ ИСКРИВЛЕНИЯ И ПРОВЕДЕНИЯ АКУСТИЧЕСКИХ ИЗМЕРЕНИЙ	222-225
Sharibaev Nosir Yusubjanovich, Djuraev Sherzod Sobirjanovich, To'xtasinov Davronbek Xoshimjon o'g'li, PRIORITIES IN DETERMINING ELECTRIC MOTOR VIBRATION WITH ADXL345 ACCELEROMETER SENSOR	226-230
Mukhammadjonov A.G., ANALYSIS OF AUTOMATION THROUGH SENSORS OF HEAT AND HUMIDITY OF DIFFERENT DIRECTIONS	231-236
Эрматова Зарина Кахрамоновна, АКТУАЛЬНОСТЬ ПРЕПОДАВАНИЯ ЯЗЫКА ПРОГРАММИРОВАНИЯ C++ В ВЫСШИХ УЧЕБНЫХ ЗАВЕДЕНИЯХ	237-241
Saparbaev Rakhmon, ANALOG TO DIGITAL CONVERSION PROCESS BY MATLAB SIMULINK	242-245
Садикова М.А., Авазова Н.К., САМООБУЧЕНИЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА, БАЗОВЫЕ ПРИНЦИПЫ РАБОТЫ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА НА ПРОСТОМ ПРИМЕРЕ	246-250
Abduhafizov Tohirjon Ubaydullo o'g'li, Abdurasulova Dilnoza Botirali kizi, DEVELOPMENT OF ALGORITHMS IN THE ANALYSIS OF DEMAND AND SUPPLY PROCESSES IN ECONOMIC SYSTEMS	251-256
Kayumov Ahror Muminjonovich, CREATING MATHEMATICAL MODELS TO IDENTIFY DEFECTS IN TEXTILE MACHINERY FABRIC	257-261
Mirzakarimov Baxtiyor Abdusalomovich, Xayitov Azizjon Mo'minjon o'g'li, BIOMETRIC METHODS SECURE COMPUTER DATA FROM UNAUTHORIZED ACCESS	262-266
Soliyev B., Odilov A., Abdurasulova Sh., Leveraging Python for Enhanced Excel Functionality: A Practical Exploration	267-271
Жураев Нурмахамад Маматович, Системы Электроснабжения Оборудования Предприятий Связи: Надежность и Эффективность	272-276
Rasulova Feruzaxon Xoshimjon qizi, Isroilov Sharobiddin Mahammadyusufovich, OLIY TA'LIM MUASSASALARIDA MUTAXASSISILIK FANLARINI O'QITISHDA MULTIMEDIALI MOBIL ILOVADANDAN FOYDALANISHNING STATISTIK TAHLILI	277-280
Muxtarov Farrux Muxammadovich, Toshpulatov Sherali Muxamadaliyevich, SUN'IY INTELLEKT YORDAMIDA IJTIMOYIY TARMOQ MONITORINGI TIZIMINI YARATISH, AFZALLIKLARI VA MUHIM JIXATLARI	281-285
Sadikova Munira Alisherovna, APPLICATION OF ARTIFICIAL INTELLIGENCE DEVICES IN MANUFACTURING	286-290
Mamatov Narzullo Solidjonovich, Ibroximov Sanjar Rustam o'g'li, Fayziyev Voxid Orzumurod o'g'li, Samijonov Abdurashid Narzullo o'g'li, SUN'IY INTELLEKT VOSITALARINI TA'LIMNI NAZORAT QILISH VA BAHOLASHDA QO'LLASH	291-297

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

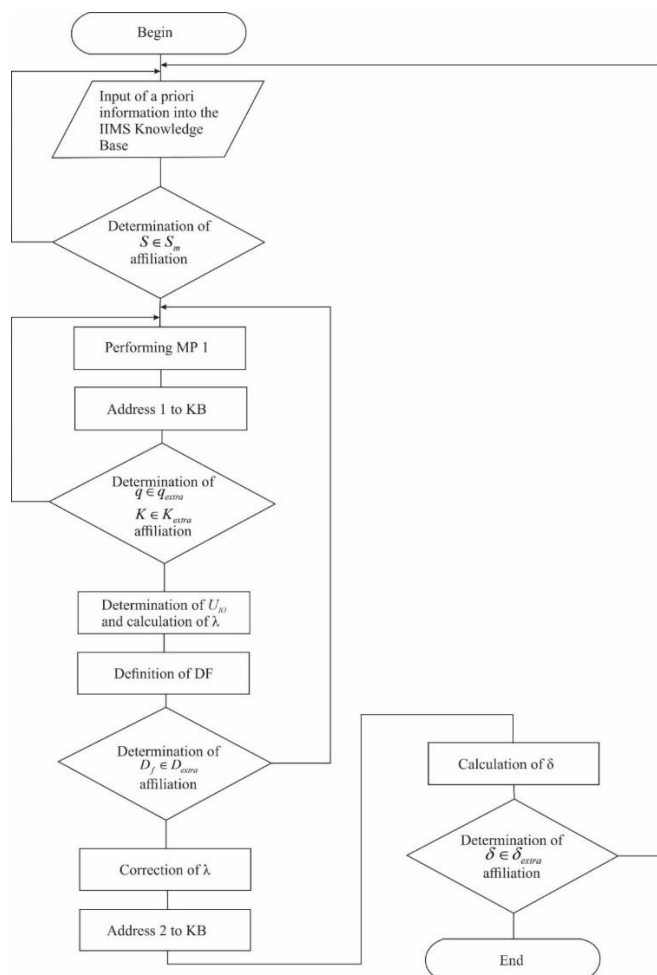


Fig. 1. Block diagram of the algorithm of realization of tolerance control of mode parameters and initial materials when determining the thermal conductivity of materials

Calculation of parameters of thermophysical properties of materials - thermal conductivity coefficients (λ) and thermal diffusivity (σ) (indication of λ and σ 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 σ 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 σ ($\Delta_{\max} \lambda_j, \Delta_{\max} \sigma_j$) 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).



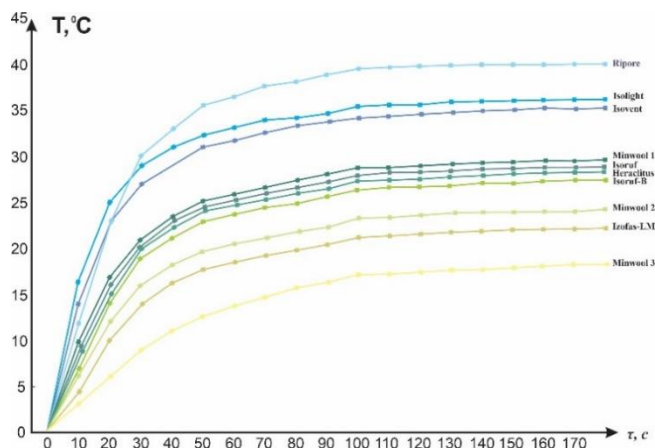


Fig. 2 Thermograms of investigated materials

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 τ_{er}^* we introduce an optimality criterion that takes into account losses of accuracy and operability in a complex way, namely

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

where C_1, C_2 are weight coefficients.

The variation of the criterion $J = (M, O)$ 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.

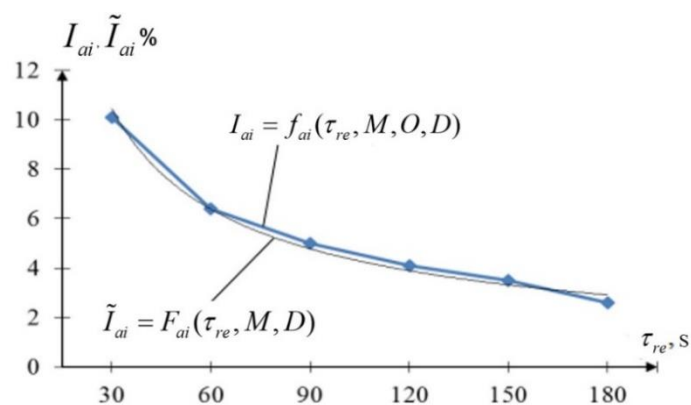


Fig. 3 Graph of dependencies of $I_{ai} = f_{ai}(\tau_{re}, M, O, D)$ and approximating function $\tilde{I}_{ai} = F_{ai}(\tau_{re}, M, D) = 10.459\tau_{re}^{-0.713}$

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

Object s under study	$\lambda_{rv}, Vt / m$	$K_{m}, Vt / m$	$K\%,$	$I_{ai}, \%$	$I_{ri}, \%$
Ripore	0,028	0,0282	0,71 42	7,01 23	18,23 41
Heraclitus	0,035	0,0348	0,57 14	6,01 01	16,21 21
Isolight	0,032	0,0323	0,93 75	2,31 11	11,11 11
Isoruf	0,034	0,0337	0,88 24	2,24 20	11,22 00
Isoruf-B	0,035	0,0347	0,85 71	2,71 31	12,11 00
Izofas-LM	0,039	0,0394	1,02 56	5,42 21	15,23 40

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.



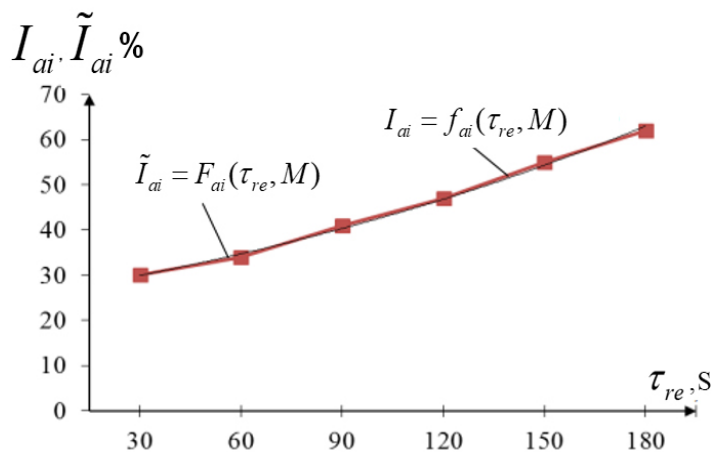


Fig. 4 Graph of dependencies of $I_{ai} = f_{ai}(\tau_{re}, M)$ and approximating function $\tilde{I}_{ai} = F_{ai}(\tau_{re}, M) = 25.791e^{0.1488\tau_{re}}$

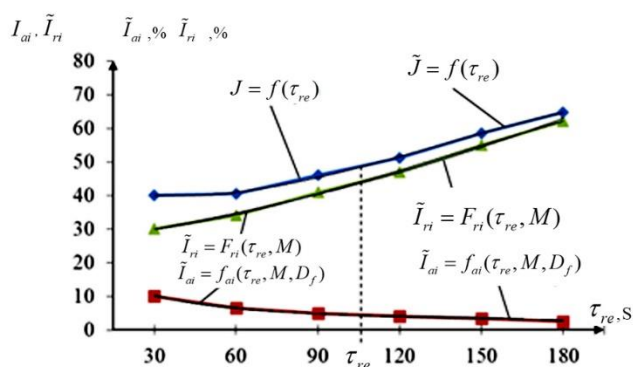


Fig. 5 Graph of dependencies of $J = f(\tau_{re}, O_{RMM})$ and approximating function $\tilde{I}_{ai} = f_{ai}(\tau_{re}, M, D_f) = -(0.1255)\tau_{re}^3 + 1.6236\tau_{re}^2 - 7.4652\tau_{re} + 16.007$; $\tilde{I}_{ri} = F_{ri}(\tau_{re}, M) = -(0.1019)\tau_{re}^3 + (1.4087 \cdot 10^{-4})\tau_{re}^2 - 0.9392\tau_{re} + 27.667$; $\tilde{J} = F(\tau_{re}) = -(0.2273)\tau_{re}^3 + 3.0323\tau_{re}^2 - 6.5261\tau_{re} + 43.673$.

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	$\lambda_{rv}, Vt/m$	$\lambda_m, Vt/m$	$K, \%$	$\Delta_{I_{ai}}, \%$	$\Delta_{I_{ri}}, \%$
Ripore	0,028	0,0283	1,07 14	2,98 77	31,7 659
Heraclitus	0,035	0,0345	0,93 75	3,98 99	33,7 879
Isolight	0,032	0,0323	1,56 25	7,68 89	38,8 889
Isovent	0,032	0,0315	2,05 88	3,11 22	33,1 123
Isoruf	0,034	0,0347	1,81 81	7,75 80	38,7 800
Minwoo 1 1	0,033	0,0324	1,62 31	1,90 10	38,9 100
Minwoo 1 2	0,037	0,0364	2,50 00	1,62 34	36,9 895
Minwoo 1 3	0,04	0,0410	1,76 47	2,51 23	34,9 674
Isoruf-B	0,035	0,0346	1,76 47	7,28 69	37,8 900
Izofas-LM	0,039	0,0397	1,79 49	4,57 79	34,7 660

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 $\Delta PT = 6\%$) of nondestructive control of thermophysical properties of thermal insulation materials.

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