Simulation of the thermophysical experiment with remote control to determine the quality properties of the object

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Abstract. Simulation of the thermophysical experiment for determination of thermophysical properties of insulating materials using the impulse method in the influence of a linear heat source on the test material and mathematical model of the process of thermophysical measurement is fulfilled in MathCad software. As a result of the simulation the optimum operating parameters for thermophysical measurements are determined: optimum operating parameters and thermal pulse repetition time interval in minimum measurement error of coefficients of thermal conductivity and thermal diffusivity of materials. The structure of an intelligent information-measuring system of remote control is offered that realizes the structure of an intelligent information-measuring system of remote control using methods of artificial intelligence that let us increase the efficiency and accuracy of determining the thermophysical properties of insulating materials.

1. Introduction
The use of energy-efficient thermal insulation of buildings and structures using thermal insulation materials reduces heating costs by 50% and reduces energy losses by 5-7 times. Energy saving is proved by external and internal structures of facilities and heat supply lines by thermal insulation materials that can keep their thermal insulation properties more than 6-7 decades.

Aims of remote control show the concept of integrated application of remote control methods, hardware and software, methods of artificial intelligence for telemetric collection of measuring information from sensors controlling quality parameters of heat-insulating materials in remote mode. Usage of the distributed object oriented intelligent information measuring system (IIMS) of non-destructive testing of thermophysical properties of insulating materials (TP) that implements the intelligent procedure for selecting optimal operating parameters using methods of artificial intelligence, creation of a telecommunication environment will let us fulfill the continuous or periodic monitoring and analysis of the quality properties of energy-efficient materials [1].

IIMS using methods of the artificial intelligence are considered in works of famous foreign scientists - founders of smart dimensions, smart environments and smart environments (Ambient Intelligence & Smart Environments) – D Hofman, D F Lugers [2-3]. Questions on intelligent information measuring systems are set up in works of Russian scientists V N Romanov, V S Sobolev, V I Tsvetkov, G G Rannev [4]. Information measuring system Unitherm TM 2022 [5] is described in the article of L Laghi, F Penecchi and G Raiteri. Analysis of these works shows that given IIMS have
not high enough speed and significant measurement error of the studied parameters set by exposure to destabilizing factors. Known impulse thermal methods of TP unbreakable control of insulating materials [6-9] are also low efficient.

That’s why the aim of this investigation is to increase the efficiency and accuracy of the applied pulse method of a linear heat source and IIMS for determination of thermophysical properties of insulating materials as a result of determination of optimal operating parameters of thermophysical measurements on MatCad software.

Remote monitoring of the quality of thermal insulation materials of buildings, structures and other structures in various operating conditions during exposure to destabilizing factors is actual and necessary for timely detection of violations of proper thermal insulation of the object [10].

2. Materials and methods

Mathematical model of thermophysical measurements is made using IIMS to determine TP of insulating materials. Using the experimental data the information at the input and output of component components of IIMS the set of limitations is calculated imposed on accuracy indicators and parameters of TP of investigated objects if they have measurement errors of thermal conductivity and thermal conductivity coefficients ($\lambda$, $\alpha$) in permissible values $\Delta\lambda_{per}$, $\Delta\alpha_{per}$:

$$\Delta\lambda(S/x_{kX}, P_{kP}, b_{kB}) \leq \Delta\lambda_{per}$$

$$\Delta\alpha(S/x_{kX}, P_{kP}, b_{kB}) \leq \Delta\alpha_{per}$$

where $\Delta\lambda(S/x_{kX}, P_{kP}, b_{kB})$, $\Delta\alpha(S/x_{kX}, P_{kP}, b_{kB})$ – respectively, the measurement error is $\lambda$, $\alpha$; $S$ – the set including components of IIMS; $x_1, x_2, \ldots, x_{kX}$ – input signals; $P_1, P_2, \ldots, P_{kP}$ – destabilizing factors; $b_1, b_2, \ldots, b_{kB}$ – parameters appropriating to the $S$ set.

Application of the mathematical model of measurements in IIMS let us set the state of the system at specified times, subsystem output dependencies of IIMS from the impact of input and patterns of influencing factors.

Dependency system is a mathematical model of measurement based on constraints (1)

$$y_1(T) = f_1(x_1, x_2, \ldots, x_{kX}; P_1, P_2, \ldots, P_{kP}; b_1, b_2, \ldots, b_{kB}; t),$$

$$y_2(T) = f_2(x_1, x_2, \ldots, x_{kX}; P_1, P_2, \ldots, P_{kP}; b_1, b_2, \ldots, b_{kB}; t),$$

$$\ldots$$

$$y_{n/bp}(T) = f_1(x_1, x_2, \ldots, x_{kX}; P_1, P_2, \ldots, P_{kP}; b_1, b_2, \ldots, b_{kB}; t),$$

where $y_1(T), y_2(T), \ldots, y_{n/bp}(T)$ – a lot of generated signals at the outputs of each subsystem (2); $t$ – signal monitoring time.

Determination of thermophysical properties of materials is determined as a result of using the method of a linear instantaneous source of thermal effect on the studied object in IIMS. In this case the heat conduction problem has the following solution [1]:

$$T(x, \tau) = \frac{Q}{4\pi\lambda\tau} \exp\left(\frac{-x^2}{4\alpha\tau}\right),$$

where $T(x, \tau)$ – temperature value; $Q$ – value of the heating power of the object of study; $\tau$ – measurement time; $x$ – distance from the controlled point to the linear heat source.

At putting $n$ - impulse in the set points of time temperature values are detected $T_n$ and $T_m$. Temperature calculation (3) in pulse frequency thermal effect on the thermal insulation material is exercised according to:

$$T(x, n) = \frac{QF}{4\pi\lambda} \sum_{i=1}^{n-1} \exp\left(-\frac{x^2}{4\alpha\Delta\tau\Delta t}\right),$$

2
where $F$ – set frequency of thermal pulses.

Formulas for determination $\lambda$ and $\alpha$ are obtained in accordance with (4) at temperature data $T(x,n)$ and $T(x,m)$ [1] as a result of thermophysical studies:

$$\alpha = B_2 \exp \left( \frac{B_3}{T_m} \right); \quad \lambda = \frac{1}{T_m} B_1 \ln(B_4 \alpha).$$  

(5)

The structure of an intelligent information measuring system offered here and making non-destructive testing of thermophysical properties of energy-efficient heat-insulating materials - coefficients of thermal conductivity and thermal diffusivity in remote control mode. On figure 1 there is a structural scheme of IIMS for TP materials. Parameter control of TP is fulfilled in the manufacturing facility of mineral wool production at the process line output.

![Figure 1. Block diagram of an intelligent information-measuring system for remote control of thermal insulation materials: RC – remote control, TM – thermal insulation materials, DF – destabilizing factors, IO – investigated object.](image-url)
Produced mineral wools – heraclitus, isovent, isoruf, isofas, etc. are not very much different in terms of thermal conductivity: from 0.03 to 0.05 W/m°C. For precise control TP parameters of mineral wool the IIMS decision block makes procedures to select optimal (rational) power values for thermal effect on the studied objects and optimal time gaps between thermophysical measurements based on production rules written in system knowledge base. Preset optimum operating parameters in the device for processing data from the studied object on the base of microcontroller with the help of controlling system are transferred to the intelligence measuring probe during thermophysical measurements with the help of linear instantaneous heat source method. Information given from the studied materials comes into intelligent information measuring system through the channel switch and radio modem. Processing of measurement data and calculation of parameters of heat-insulating materials - coefficients of thermal conductivity and thermal diffusivity is fulfilled in IIMS. If calculated values of TP are different from permissible values mentioned in documentation on the materials this information comes to the technological department of the enterprise for making decision to correct technological process. Analysis, statistical processing of measurement information of studying objects and its keeping is fulfilled by PC and is used for further improvement of the technological process for the manufacture of insulating materials.

3. Results and discussions

Developed a mathematical model of the process of thermophysical measurements making possible to establish the dependence of the input signals of the structural components of the system from the input signals distinguishing the account of the influence of destabilizing factors and restrictions on the errors in determining the coefficients of thermal conductivity and thermal diffusivity.

Based on the mathematical measurement model (2) and dependencies (5) the process of simulation thermophysical parameter measurements was made in MatCad software. As a result of the simulation the graphs of the dependencies of the errors of the measurement of thermal conductivity (figure 2a) and thermal diffusivity (figure 2b) on the power of thermal exposure were determined, as well as the dependence of the errors in the measurement of coefficients $\lambda$ (figure 3a) and $\alpha$ (figure 3b) from the time interval $\tau_{int}$.

![Graphs of dependencies of errors](image)

**Figure 2.** Graphs of dependencies of errors in the measurement of the coefficients of thermal conductivity (a) and thermal diffusivity (b) on the power of thermal exposure $Q_{PMM}$ – polymethylmethacrylate.
Figure 3. Graphs of dependencies of errors in the measurement of the coefficients of thermal conductivity (a) and thermal diffusivity (b) on the time interval $\tau_{int}$.

According to results of analysis of the given dependencies on figures 2-3 optimal heat output power for the studied object and time interval are selected between conducting thermophysical measurements with a minimum measurement error of the coefficients of thermal conductivity and thermal diffusivity.

Results of simulation in MatCad software are used in the intelligent information measuring system to select optimal parameter modes that 3-5 times exceed the efficiency of parameter determination of TP in permissible error of not more than 5%.

The obtained results on the selection of optimal operating parameters when determining the coefficients of heat and thermal diffusivity have a scientific novelty and an advantage in efficiency and accuracy compared with the known characteristics of conducting thermophysical experiments [6-9].

4. Conclusion
The structure of the intellectual measurement system is offered, the difference of which is lies in the application of a mathematical model of thermophysical measurements and simulation results in MatCad software for making decisions in conditions of uncertainty when exposed to destabilizing
factors at determination of optimal operating parameters of the process of thermophysical measurement using an intelligent measuring probe.

Obtaining real-time and accurate information about the thermophysical properties of materials in real time helps to improve the quality and reduce the percentage of marriage of manufactured heat-insulating materials.

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