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INSTALLATION FOR DETERMINING THE THERMAL CONDUCTIVITY OF PLATES BY THE STATIONARY METHOD

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When measuring the thermal conductivity of thermal insulation materials made by powder metallurgy and building porous materials, complications arise due to the fact that heat flows through the samples are commensurate with heat losses. The steady-state heat flow (SSHF) method is simple, does not require sophisticated equipment, and allows determining the thermal conductivity not in the near-surface layer but in the entire sample volume. Its disadvantage is low accuracy and the need to use reference samples.

This work aims to develop an installation for measuring the thermal conductivity of large-sized samples of low-conductivity material using the steady-state heat flow method with significantly higher accuracy than existing installations using this method.

This is achieved by sandwiching the sample, which is a thin square plate of large dimensions, between the heater chamber and the refrigerator. The heating chamber is made of insulating material and its front wall, which is in contact with the sample, is made of the copper plate (which has good thermal conductivity). In the operating mode, the temperature in the heater chamber is maintained equal to the ambient temperature, which allows us to neglect heat losses and assume that in the steady-state mode, the heater power is equal to the heat flux through the sample. The thickness of the sample is much smaller than the size of its side (the sample should be square). This assumption is necessary to use the condition of isotropic temperature distribution in the cross-section of the sample. The refrigerator is filled with water and ice. The isotropic temperature distribution in the sample is ensured by its contact with the copper walls of the heater and refrigerator chamber. The temperature of the heated surface of the sample is measured using a thermocouple inserted through a hole in the front wall of the heater chamber.

The proposed design of the installation and its operating conditions make it possible to significantly improve the accuracy of determining the thermal conductivity coefficient and make the error less than 2%.

Key words: *thermal conductivity, steady-state heat flow, building materials.*

Івашина Ю. К., Заводянний В. В. Установка для визначення теплопровідності пластин стаціонарним методом

При вимірюванні теплопровідності теплоізоляційних матеріалів, виготовлених методами порошкової металургії, та будівельних пористих виникають ускладнення, обумовлені тим, що теплові потоки через зразки співрозмірні з тепловими втратами. Метод стаціонарного теплового потоку (СТП) простий, не вимагає складного обладнання, дозволяє визначити теплопровідність не в приповерхневому шарі, а в усьому об'ємі зразка. Недоліком його є низька точність і необхідність застосування еталонних зразків.

Метою роботи є розробка установки для вимірювання теплопровідності зразків значних розмірів із матеріалу з низькою теплопровідністю методом стаціонарного теплового потоку із суттєво вищою, ніж у існуючих установок, які використовують цей метод, точністю.

Це досягається тим, що зразок, який представляє собою тонку квадратну пластину великих розмірів, затискається між камерою нагрівника і холодильником. Камера нагрівника виготовлена із теплоізоляційного матеріалу, а її передня стінка, з якою контактує зразок, із мідної пластини (що має добру теплопровідність). В робочому режимі температура в камері нагрівника підтримується рівною температурі оточуючого середовища, що дозволяє знехтувати тепловими втратами і вважати, що в стаціонарному режимі потужність нагрівника дорівнює потоку теплової енергії через зразок. Товщина зразка значно менша за величину його сторони (зразок повинен мати форму квадрату). Таке допущення необхідне для використання умови ізотропного розподілу температури в поперечному перерізі зразка. Холодильник заповнюється водою із льодом. Ізотропний розподіл температури в зразку забезпечується його контактом з мідними стінками камери нагрівника і холодильника. Температура нагрітої поверхні зразка вимірюється з допомогою термопари, яка вводиться через отвір в передній стінці камери нагрівника.

Запропонована конструкція установки і умови її експлуатації дозволяють суттєво підвищити точність визначення коефіцієнта теплопровідності і зробити похибку меншою 2%.

Ключові слова: *теплопровідність, стаціонарний тепловий потік, будівельні матеріали.*

Introduction. Thermal conductivity is an important characteristic of structural and heat-insulating materials, so its experimental determination is of considerable practical importance. Particular difficulties arise when measuring the thermal conductivity of thermal insulation materials made by powder metallurgy and building porous materials such as polystyrene foam, aerated concrete, etc. since the heat fluxes through them are commensurate with parasitic heat losses. In addition, to eliminate the error caused by the heterogeneity of the structure, measurements must be performed on massive samples, which causes an increase in heat losses.

There are three classes of thermal conductivity measurement methods: steady-state, non-steady-state, and frequency. The advantage of the steady-state heat flux method is its simplicity, low cost, and the ability to measure the thermal conductivity of materials with any electrical conductivity. The disadvantages of the method are its low accuracy and the need to use reference samples [1]. The error in determining the thermal conductivity coefficient by this method reaches 10%.

The steady-state heat flux method is based on the passage of heat flux through the test sample and two standards with known thermal conductivity coefficients [1, 2]. The accuracy of the STF method is determined by the accuracy of determining the temperatures at the boundary between the test and reference samples, the error in the values of the thermal conductivity coefficient λ of the reference samples, and their selection. The coefficient λ of the reference should be close to λ of the test sample. It is also important to take into account heat losses at the contacts between the samples.

An example of a non-stationary method is the method of a flat "instantaneous" heat source, which is indirect [3]. In addition to the traditional sources of errors that exist in the measurement of thermal conductivity, there are additional errors in the measurement of current temperature values $T(x_0, \tau)$, electrical power, and the duration of the thermal pulse [4]. Indirect methods are also used, based on the fact that the surface of the body under study is exposed to microwave radiation [5]. The method requires sophisticated equipment, uses complex mathematical models and calculations. The methods of probe microscopy and laser flash have similar disadvantages. In addition, they are used to determine the thermal conductivity in the near-surface layer of the sample.

This work aims to develop an installation for measuring the thermal conductivity coefficient λ of massive flat samples with low thermal conductivity using the steady-state heat flow method with a significantly higher accuracy of determining λ than existing installations using this method.

Research results. The accuracy of the thermal conductivity coefficient determination by the STP method can be improved by eliminating heat loss flows and refusing to use reference samples, i.e., by using the direct measurement method. Heat losses from the heater are caused by heat conduction through imperfect insulation and radiation. It is especially important to eliminate parasitic heat fluxes when studying samples with low thermal conductivity when the thermal resistance of the insulation is commensurate with the similar resistance of the sample. We have proposed a solution to this problem by contacting the sample with a heater chamber inside which the ambient temperature is maintained [6]. The setup consists of two separate isolated parts. In one part (the heater chamber), an air heater is mounted, which maintains the ambient temperature inside the chamber tc. The second part is a refrigerator. The installation scheme is shown in Fig. 1.

The heater chamber *1* is made of heat-insulating material. We used 0.05 m thick polystyrene foam. The front wall *2 of the* chamber is a copper plate $2–10^{-3}$ m thick, against which test sample *3 is* pressed. Heater *4* is a manganese spiral. Its power depends on

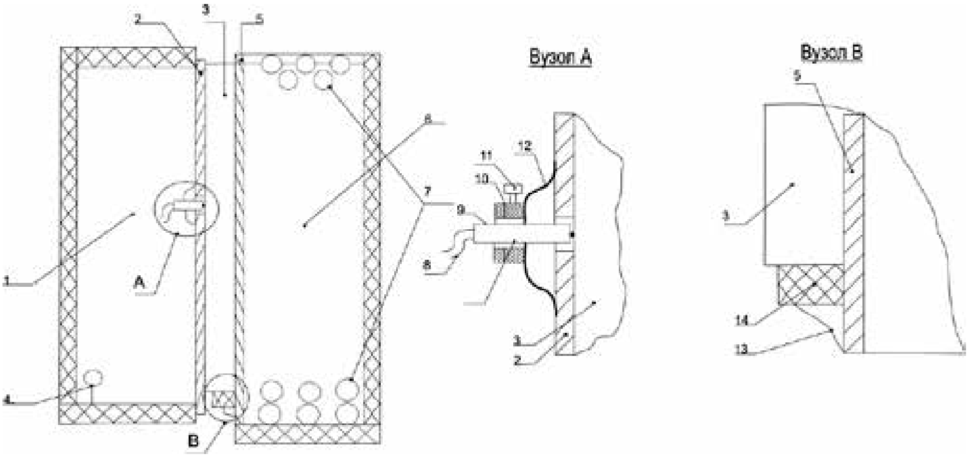

Fig. 1. Scheme of the installation for measuring thermal conductivity
1 – heater chamber, 2 – chamber wall, 3 – test sample, 4 – heater, 5 – refrigerator wall, 6 – refrigerator, 7 – ice, 8 – thermocouple, 9 – ceramic tube, 10 – thermocouple holder, 11 – screw, 12 – spring clip, 13 – stop, 14 – thermal insulation

the size and material of sample *3* and is only a few watts. For uniform heating of the air in the chamber, the length of the heater is close to the width of the chamber.

The temperature in the heater chamber is measured using a temperature sensor installed in its center. The dimensions of the chamber depend on the dimensions of the sample, which is a square plate with *a* side $a = 0.1 \div 0.2$ m.

The cross-sectional dimension *b is* limited by the conditions of convective heat transfer in the heater chamber and the placement of the heater and temperature sensors and is about $0.5a$. In order to neglect the heat exchange of sample *3* with the environment through the side surface, the thickness of the sample must be significantly less than *a*. This assumption is necessary to use the condition of isotropic temperature distribution in the cross-section of the sample. This is ensured by the fact that the sample with low thermal conductivity is in contact with the heater chamber and the refrigerator through copper plates *2* and *5*.

In the operating mode, the temperature in the center of chamber *1* is maintained equal to the ambient temperature t_c. Due to the thermal insulation of the chamber walls and the maintenance of the temperature inside equal to t_c, the heat fluxes of losses can be neglected, and it can be assumed that in the stationary mode, the heater power is equal to the heat flux transferred through the plate *2* to the test sample *3*. Since there is a vertical gradient of air temperature in the heater chamber, the air temperature in its upper part will be $t_c + \Delta t_1$ and in the lower part $t_c - \Delta t_1$. Accordingly, the heat fluxes through the chamber enclosure in its upper and lower parts will be compensated.

A differential copper constant thermocouple *8 is* used to determine the temperature of the heated surface of the sample, which is mounted in a two-channel ceramic tube *9* and pressed against the sample by a beryllium bronze spring bracket *12. The* clamping force is adjusted by means of screw *11* by moving tube *9* in the thermocouple holder *10*. The junction of the thermocouple is in contact with the sample through the hole in plate *2*. This scheme of installation of the thermocouple ensures not only its reliable contact with the sample but also eliminates heat dissipation through the thermocouple due to thermal contact of the thermocouple holder with plate *2*. Due to the fact that its thermal conductivity is much higher than that of the sample, the temperature of the sample surface in the vertical direction is equalized. Since the vertical temperature distribution is symmetrical with respect to the central axis of the sample, the average temperature of the heated surface of the sample will be equal to the temperature in its center and is measured by thermocouple *8*. Several thermocouples can be installed for large samples. Since the temperature in chamber *1 is* equal to the ambient temperature, the heat fluxes through the thermocouple and heater terminals can also be neglected.

The refrigerator *6 is* filled with water and ice *7*. To eliminate the vertical temperature gradient, part of the ice floats on top, while the other is placed in a grid with weight and sinks to the bottom. The wall of refrigerator *5,* which is in contact with the sample, is made of a copper plate, and its temperature is fixed at 0 °C. The test specimen *3 is* attached to the refrigerator and held by means of stops *13,* which are attached to the wall of refrigerator *4* and separated from the specimen by thermal insulation *14*. The stops are made of plastic and also act as a heat shield, which reduces the heat flow through the side surface of the sample. The refrigerator with the sample is leaned against the heater chamber. The side surface of the sample is insulated with mineral wool tape. The easiest way to clamp the sample between the heating chamber and the refrigerator is to use rubber straps. Alternatively, springs attached to brackets mounted on the heater chamber and refrigerator can be used.

The proposed setup is designed to determine the thermal conductivity coefficient λ of materials with low thermal conductivity. Its advantages are sufficient simplicity, the ability to perform measurements in a stationary mode on samples of large sizes, which eliminates the influence of sample material inhomogeneities, and the lack of reference samples. The design and operating conditions of the installation allow to minimize heat loss fluxes. Significant geometric dimensions of the sample significantly reduce the error of their determination. These factors can significantly reduce the error in determining λ. The use of a stabilized heater power supply, thermocouple calibration, and the use of high-end measuring instruments will allow determining the thermal conductivity coefficient with an error not exceeding 2%.

The disadvantages of the installation include the limitation of the thermal conductivity of the samples from above since at high values, the significant heater power is required and difficulties will arise in using the stationary mode. To determine the thermal conductivity of samples at higher temperatures, the heater chamber must be placed in a thermostat, and the temperature of the refrigerator must be higher accordingly. This complicates the installation and measurement process.

Conclusions. A scheme of an installation for measuring the thermal conductivity of plates by the steady-state heat flow method has been developed, which does not require reference samples and has a much higher accuracy. A significant reduction in heat losses is due to the fact that the ambient temperature is maintained inside the heater chamber, with which the test sample is in contact, which makes the error in determining the thermal conductivity coefficient less than 2%.

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