Experimental research on the thermal conductivity of the contact pads for electronic equipment

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Abstract. Currently, soft contact pads of foreign manufacturers of SIL-Pad, Gap-Pad and Bond-Play series are widely used to transfer heat flows in electronic equipment elements. Within the framework of import substitution programs, the technology of manufacturing analogs of heat-conducting gaskets from local raw materials is being developed. The main thermal property that determines the performance of gaskets is the thermal conductivity. The article describes the installation, technique and methods of conducting and processing the results of experiments developed for its determination. The analysis of the obtained experimental data is made.

1. Introduction
Object of research – heat strip domestic counterparts series of SilPad, GapPad and Bond-Play (hereinafter test samples). The main objective of the study: to determine such thermal characteristics as thermal conductivity, thermal resistance of three types of prototypes in a wide temperature range, including under variable external load.

2. Description of installation
To study the thermal conductivity of the prototypes, an experimental unit has been built that implements the known method of a flat layer at a stationary heat flow [1]. The range of operation from −60°C to +150°C, in addition, the measuring cell for the study of thermal conductivity is designed to measure the load of the sample with an overpressure of up to 1200 kPa. In order to avoid thermal leakage from the sample due to natural convection, the measurement cell is vacuumed, which also ensures the absence of condensation and freezing of water vapor from the ambient air inside the cell in the negative temperature range. Achievement, regulation and keeping of stationary regimes with the aim of measuring the EMF of the thermocouples was provided by the laboratory thermostat of UT-15 with silicon organic coolant PMS 1.5R. Heating of the coolant is carried out by an electric heater, cooling-with the help of liquid nitrogen, which was supplied from the Dewar vessel. The scheme of measurement cell is given in figure 1. The heat flow is provided by the heater 1 from the DC power supply B5-47 with adjustable load within the task 2.8–3.6 V. the Power of the heat flow along the copper rod 2 with a diameter F4, 1 is determined by the differential copper-copper thermocouple and the distance between its ends (39 mm). The EMF signal is supplied to the precision voltmeter V7-65/1. Moreover, as the copper conductors of this thermocouple is the rod material copper M1. The temperature difference on the sample 3 is also controlled by a differential copper-kopel thermocouple, the
Figure 1. The scheme of measurement of EMF thermocouples on the installation for the study of thermal conductivity.

EMF signal of which is fixed by a precision voltmeter Sh-31. The temperature of the copper substrate 4 of the test sample is controlled by a chromel-kopel thermocouple, the signal of which is fixed by the measuring unit OVEN TRM-1.

3. The procedure for the experiment and the processing of the results of thermal conductivity measurement

The test sample 3 is placed between two flat copper plates – the lower one, which provides the temperature conditions of the experiment due to contact with the cell body) and the upper one, which provides the heat flow to the test sample. The thermal conductivity ($\lambda$) of the sample is determined by the formula:

$$\lambda = \frac{Q \delta}{(f \Delta t)},$$  

where $Q$ – is the heat flux passing through the sample; $\delta$ – is the thickness of the sample; $f$ – is the contact area of the sample with the plates; $\Delta t$ – is the temperature difference between the plates. The thermal conductivity value should be assigned to the middle of the temperature range between the plates. The heat flux was measured using a calibrated copper rod (2) made of electrical copper. To determine the value of heat flux at a known mutual distance on the pole kopleva conductors. The temperature difference during the passage of heat flow through the rod corresponds to the difference thermo-EMF of copper-copilului differential thermocouple. EMF value was measured by digital voltmeter V-7-65/2. The value of the heat flux was determined as

$$Q = \lambda_c U_t k f_r / x,$$

where $\lambda_c$ – is the thermal conductivity of copper; $U_t$ – is the thermal EMF of a differential thermocouple; $k$ – is the electrothermal coefficient; $f_r$ – is the cross-sectional area of the copper rod; $x$ – is the distance of the axis of the copper rod between the ends of the copper conductors. To exclude heat flow out of the measured sample, the measurements were carried out in a vacuum.
chamber an autoclave of steel 10KH18N12 from which suction air of the fore-vacuum pump (no estimation of the depth of vacuum). By means of the described method and the corresponding experimental setup certification tests in the temperature range $-30\ldots+130^\circ C$ on the control sample shall be carried out. Relative thermal resistance per unit area of one layer determined by the formula:

$$r_t = 1/\lambda,$$

where $\lambda$ W/m-K is the thermal conductivity obtained by experimentally higher the given technique. Studies of the thermal conductivity of heat-conducting gaskets under load were carried out as follows: loads were installed on a column with seals as their weight increased from minimum to maximum in accordance with a given pressure range from 200 to 1200 kPa. When removing loads, the initial and final values of thermal conductivity (without load) were compared.

4. Estimation of measurement error

The error calculation was carried out in accordance with the generally accepted method [2]:

$$\lambda_{ts} = \lambda_c(t)\Delta U_1(\partial t/\partial U)_1 f_c \delta/(\Delta U_2(\partial t/\partial U)_2 f_{ts}x),$$

where $\lambda_{ts}$ – is the conductivity of a test sample; $\lambda_c(t)$ – is the conductivity of copper; $\Delta U_1$ – is thermal EMF of the differential thermocouple, measured with a voltmeter V7-65, $\Delta U_1$ – is thermal EMF of the differential thermocouple, measured with a voltmeter Sh-31; $f_c$ – is sectional area of copper rod; $f_{ts}$ – is square cross-section test sample; $\delta$ – is the thickness of the test sample; $x$ – is the length of the control portion of the copper rod. Temperature coefficient of thermo-EMF for thermocouples of copper-Kopel type was used in the form of equation of 4 degree (GOST R8.585-2001 GSI). To find the temperature increments, the equation was differentiated. As a result, the equation of 3 degrees, having the form of temperature dependence, close to linear. The error in finding the temperature according to the standard equation is estimated $\Delta t = \pm0.5^\circ C$ in the range from $-70$ to $150^\circ C$. The error in finding the increments $\Delta(dt/dU)$ is estimated to be no worse than 0.5 mV/K. The error in measuring the thermal conductivity was calculated as:

$$\delta\lambda_{ts} = [(\delta\lambda_c)^2 + \delta U_1^2 + 2\delta U_1^2(\partial dt/\partial U)^2 + \delta f_c^2 + 2\delta f^2 + \delta f_{ts}^2 + \delta x^2]^{1/2},$$

where the following values of the relative errors have been used: the error of calculation of the thermal conductivity of copper of M1 mark GOST 859-2001 by equation 3 degree: $\delta\lambda_c = 1\%$; the error of measurement of the EMF of the differential thermocouple copper-kopel copper rod voltmeter V7-65: $\delta U = 0.1\%$; the error of measurement of the EMF of the differential thermocouple copper-kopel of the subject sample: $\delta U = 0.05\%$; the measurement error of the cross-sectional area of the copper rod using a micrometer $\delta f = 0.5\%$; the measurement error of the cross-sectional area of the test sample of the heat-conducting spacer rod-compass $\delta f = 2.7\%$; the measurement error of the thickness of the test sample rod-compass $\delta x = 3.0\%$; the measurement error of the length of the control section of the copper rod using the rod-compass $\delta h = 1.3\%$. As a result, the guaranteed error of thermal conductivity measurement will be in the range from 4% to 5%. The thickness of the manufactured soft gaskets was not technologically provided with a constant value. It changed on a sample with a diameter of 15 mm in the range up to 1 mm. Therefore, the clamping plate (the upper one was “floating”, it was on a hinge) was installed until full contact spontaneously under the load of the clamping rod. For solid reference samples, the linear dimension can be measured with a micrometer to an accuracy of 0.05 mm and the contribution of error in thickness and area of the sample can be reduced by 2–3 times.
5. Analysis of results
The results of certification experiments on solid samples are given in figure 2. They confirm the above conclusions and guarantee the accuracy of the thermal conductivity measurement on the heat-conducting gaskets.

The results of measurements of thermal conductivity in the domestic analogue of the Sil-Pad is shown in figure 3.

![Figure 2](image1.png)

**Figure 2.** The results of measurement of thermal conductivity on the reference sample and its deviation from the passport values.

![Figure 3](image2.png)

**Figure 3.** Results of thermal conductivity measurement on the domestic analogue of Sil Pad.

![Figure 4](image3.png)

**Figure 4.** Results of thermal conductivity measurement on the domestic analogue of Sil Pad under load.
An increase in the values of $\lambda$ to a pressure of 800 kPa was recorded, then they stop changing. When the load is removed, the value of $\lambda$ is restored to the initial value within 5%.

In the temperature range from $-30^\circ C$ to $+150^\circ C$, the values of $\lambda$ of domestic heat sinks exceed the passport values of the foreign analogue of Sil Pad (1.0 W/mK). With high temperatures the $\lambda$ reaches 1.3 W/mK. The results of the thermal conductivity measurement on the domestic analogue of Sil Pad depending on the load at 30°C are shown in figure 4. There are values of $\lambda$ in the absence of the load (in the beginning of the experiment) and when removing the load (in the end of the experiment).

6. Conclusion

- Installation for measuring thermal conductivity in a wide temperature range from $-30^\circ C$ to $+150^\circ C$ has been created and tested.
- The results of certification experiments on [3] confirmed its high metrological level (deviations from the passport values within 2%).
- Extensive experimental data sets for three types of heat-conducting gaskets-domestic analogues of foreign materials Sil-Pad, Gap-Pad and Bond-Play were obtained.
- In the entire temperature interval the values of $\lambda$ are higher than those of foreign models.
- After the 1000 kPa load is removed, the values of $\lambda$ are restored.

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References

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[2] GOST 8207-76 Direct measurements with multiple observations. Methods of processing the results of observations: basic provisions
[3] GOST 15130-86 Optical quartz glass (QU)