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RESULTS OF FULL-SCALE TEST OF A PROTOTYPE SYSTEM FOR NON-UNIFORM COOLING OF ELECTRONIC BOARDS

This paper is concerned with a description of a prototype system for non-uniform cooling of electronic boards and a test bench for conducting its full-scale test. The respective results of experimental research are given. Based on the full-scale test it has been determined that non-uniform cooling of electronic boards is superior to uniform one in the energy and mass-dimensional parameters. It has been established that practical use of the elaborated system requires optimizing between thermopile supply current and the amount of working agent used.

Key words: prototype, test bench, full-scale test, electronic board, thermoelectric module, non-uniform heat removal, melting agent.

Introduction

Electronic boards belong to the most popular components of modern electronic equipment. Depending on the arrangement of conductive pattern, they can be classified as single-sided, double-sided and multilayer. Irrespective of electronic board type, their basic feature is distribution along the area of heat-emitting elements. At the present time, heat removal from heat-emitting elements is based on air, liquid, evaporative and thermoelectric cooling. The list of some manufacturers of this equipment is given in Table 1. When analyzing their products as applied to heat removal from electronic boards characterized by non-uniform heat release, it should be noted that electronic equipment cooling systems based on liquid and conductive methods are little efficient owing to low intensity of heat removal and the accuracy of temperature maintenance on the required level. Liquid and evaporative heat removal systems are difficult to implement, they call for bulky and structurally complicated equipment. Thermoelectric coolers mainly realize uniform heat removal from all electronic board components and are not efficient in this application aspect either.

Therefore, based on the strongly marked temperature field non-uniformity of electronic board, the authors have proposed a cooling system for its components [20] that takes this factor into account.

The device schematic is shown in Fig. 1, and its appearance – in Fig. 2.

The device comprises a metal container filled with the working agent having high value of melting heat and melting temperature in the range of 35 to 65 °C (for instance, paraffin, wax, nickel nitrate, etc). A container accommodating an electronic board with respective heat-emitting elements has a profiled surface, with recesses formed at places of arrangement of electronic equipment components most critical to temperature operation mode or requiring considerable temperature reduction. In said recesses, thermopiles powered from DC source are placed. The recess dimensions are selected so as to match the thermopile size.

Table 1

№	Companies	Type of manufactured products	Reference
1	2	3	4
1.	AAVID Thermalloy (USA)	Liquid coolers and air heat sinks	[1]
2.	Ligra (Russia)	Pin and plate heat sinks	[2]
3.	Proton-Electrotex (Russia)	Pin and plate heat sinks	[3]
4.	Summit Heat Sinks Metal co. (Taiwan)	Pin and plate heat sinks	[4]
5.	Alutronik (Germany)	Pin and plate heat sinks, electronic equipment packages	[5]
6.	ThermoFlow (USA)	Heat sinks of all types	[6]
7.	Melcor (USA)	Thermoelectric cooling systems	[7]
8.	Marlow Inc. (USA)	Thermoelectric cooling systems	[8]
9.	FerroTec. (USA)	Thermoelectric cooling systems	[9]
10.	Fandis (Italy)	Thermoelectric cooling systems	[10]
11.	Komatsu Electronics (Japan)	Thermoelectric cooling systems	[11]
12.	Kryotherm (Russia)	Thermoelectric cooling systems	[12]
13.	Osterm (Russia)	Thermoelectric cooling systems	[13]
14.	RMT (Russia)	Thermoelectric cooling systems	[14]
15.	Evercool (Taiwan)	Fan units, liquid systems	[15]
16.	Titan (Taiwan)	Fan units, liquid systems	[16]
17.	Zalman (South Korea)	Fan units, liquid systems	[17]
18.	Sunon (Taiwan)	Fan units, liquid systems	[18]
19.	Thermaltake (Taiwan)	Fan units, liquid and evaporative systems	[19]

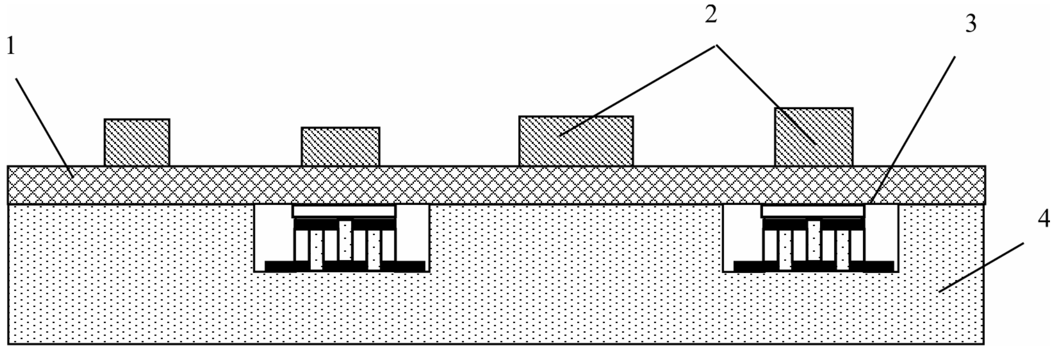

Fig. 1. Schematic of electronic board cooling with a joint use of melting working agent and thermopile (1 – electronic board, 2 – radio elements, 3 – thermopile, 4 – melting working agent container).

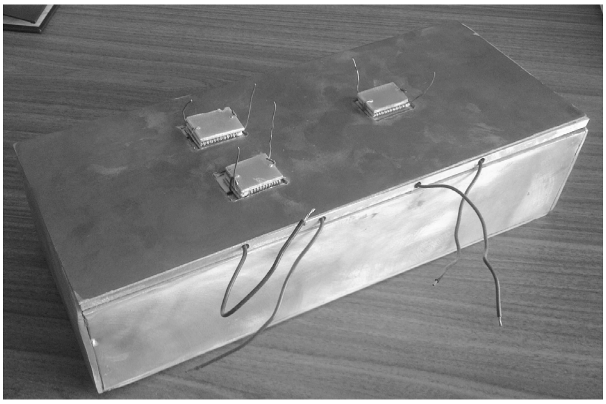

Fig. 2. Outside view of cooling device with electronic board simulator.

In device operation, heat coming from electronic equipment components placed on the electronic board is transferred to metal container and through the contact surface to the working agent. Then the working agent is heated to melting temperature, and melting process accompanied by the absorption of heat spent for change of state occurs. Heat removal due to change of state of the working agent is fundamental and can be used to assure the necessary temperature operation mode of electronic equipment components that do not require essential temperature reduction or are not critical to considerable overheat with respect to environment. For cooling electronic equipment components particularly critical to overheat or requiring essential temperature reduction, use is made of thermopiles that assure additional heat pickup, the cooling capacity value of each thermopile being determined in conformity with the heat release level of specific electronic equipment component. In so doing, heat from thermopile hot junctions is also removed to the working agent in the container the amount of which is calculated from the durability of electronic equipment components, their heat release power, thermopile heat production, as well as the operating conditions.

For device characterization an experimental bench was assembled, schematically shown in Fig. 3.

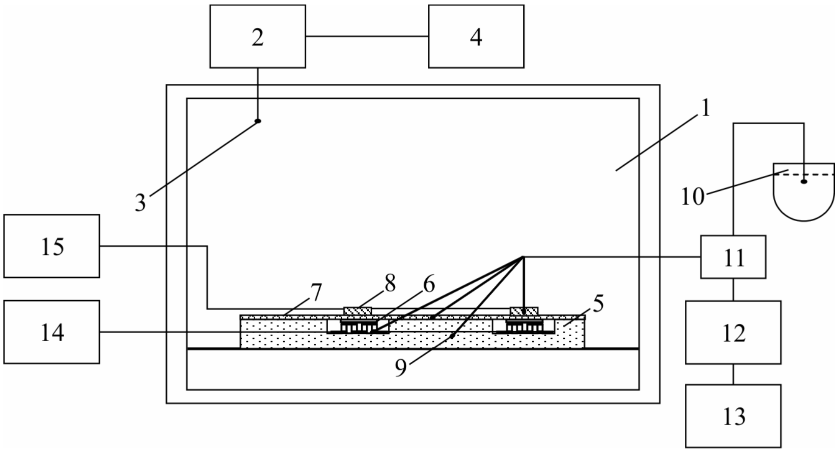

Fig. 3. Schematic of experimental bench.

Investigations were performed in thermally insulated climatic chamber 1 with thermostated working volume 120 liters. The chamber assures maintenance of temperature in the range from 283 to 343 K to an accuracy of 0.2 °C and relative humidity from 30 % to 98 %. Given temperature and relative humidity in the chamber are controlled by control unit 2 related to temperature and humidity sensor 3 whose readings are recorded by digital display 4.

The object for experimental research was a prototype cooling system in the form of a container 5 filled with the working agent, namely paraffin. The upper surface of the container is profiled, with two grooves accommodating standard TEM 6 of the type DRIFT-08. The location of the grooves corresponds to location on electron board simulator 7 of heat-emitting elements 8 represented by flat nichrome electric heaters. The topology of arrangement of heat-emitting elements on electronic board simulator is shown in Fig. 4. The simulator corresponds to electronic board of high-frequency power amplifier designed by Open JSC “P.S.Pleshakov Radio Factory” (Russia, Republic Dagestan, Izberbash city).

To determine the basic parameters of prototype under test, the following values were measured: voltage and current on TEM; their junction temperatures; voltage and current on the heaters, the temperatures at control points of electron board simulator, including the heaters, and the cover temperature of the working agent container.

The hot and cold side temperatures of TEM, as well as at control points of electron board simulator were measured by copper-constantan thermocouples 9 whose reference junctions were in Dewar vessel 10. Output signals from the thermocouples through multi-channel switch 11 came to measuring complex IRTM 12 with personal computer 13 connected to its output to register measured temperature readings at preset time intervals. TEM was powered by controlled DC source 14. Current passing through TEM and its voltage were controlled by devices embedded in power supply unit. A similar DC source 15 was used to power thermal load simulators (electric heaters).

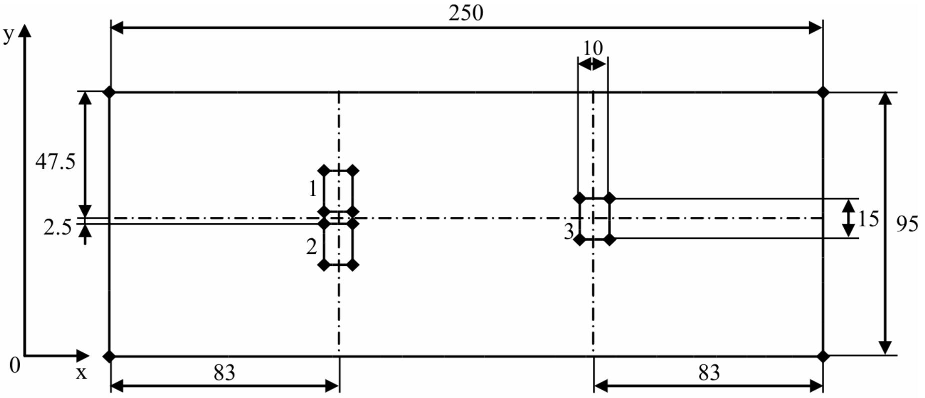

Fig. 4. Topology of electronic board simulator.

The basic task when conducting experimental investigations was to determine the temperature dependences of electronic board simulator heat-emitting elements, when non-uniformly cooled, on the TEM and working agent parameters, as well as time variation of the cover temperature of the working agent container. It was important to compare the experimental data to theoretical ones.

Figs. 5 – 6 represent the experimental dependences of temperature variation at control points of electronic board simulator in time without cooling system at different powers. For comparison, the same figures show theoretical plots obtained on the basis of elaborated mathematical model [21]. According to the data presented, the temperature of heat-emitting elements is increased considerably. Thus, for the source of heat 1 (see Fig. 2) in the steady-state mode the temperature value is 428 K with heat release power 120 W and 410 with heat release power 100 W (the temperature values for heat-emitting element 2 are the same), and for the source of heat 3 – 396 K and 382 K, respectively. In so doing, the temperature in the electronic board areas adjacent to heat sources is of the same value. In Figs. 5 and 6 its value is 415 K and 403 K, which testifies to the presence of considerable temperature background that may have an adverse effect on the operation of electron board components, namely cause their failure.

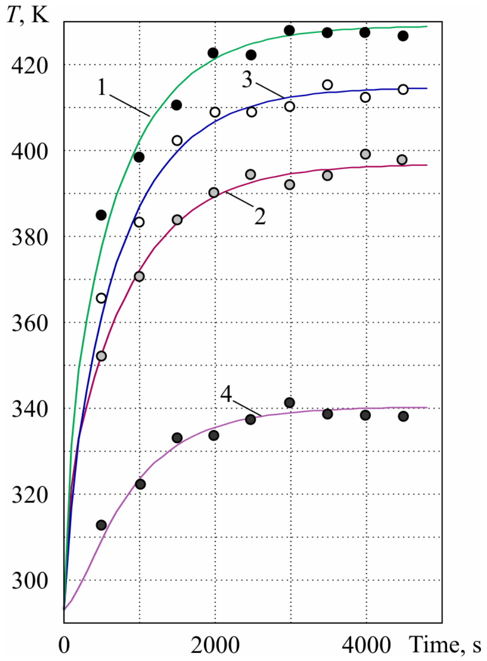

Fig. 5. Temperature variation at different points of electronic board versus time with the power of heat-emitting elements 120 W. 1 – temperature of heat source 1; 2 – temperature of heat source 3; 3 – temperature at x = 125 mm, y = 47.5 mm; 4 – temperature at x = 17 mm, y = 14 mm.

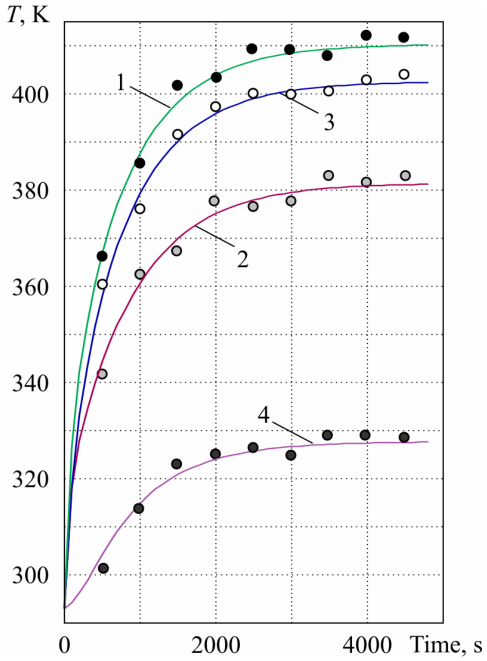

Fig. 6. Temperature variation at different points of electronic board versus time with the power of heat-emitting elements 100 W. 1 – temperature of heat source 1; 2 – temperature of heat source 3; 3 – temperature at x = 125 mm, y = 47.5 mm; 4 – temperature at x = 17 mm, y = 14 mm.

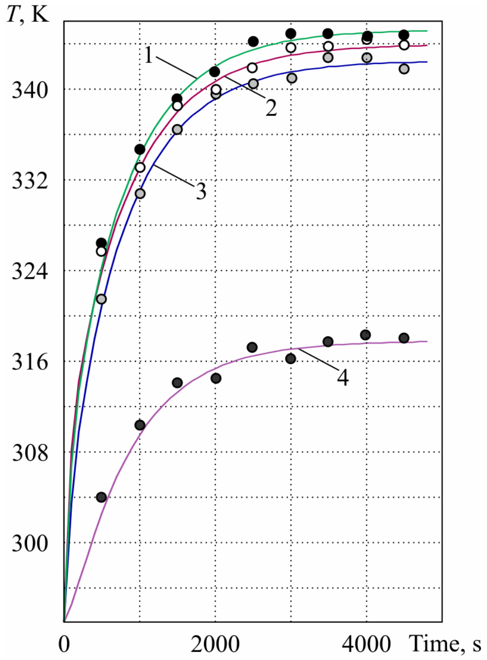

Fig. 7. Temperature variation at different points of electronic board versus time with the power of heat-emitting elements 120 W and thermopile supply 10 A. 1 – temperature of heat source 1; 2 – temperature of heat source 3; 3 – temperature at x = 125 mm, y = 47.5 mm ; 4 – temperature at x = 17 mm, y = 14mm.

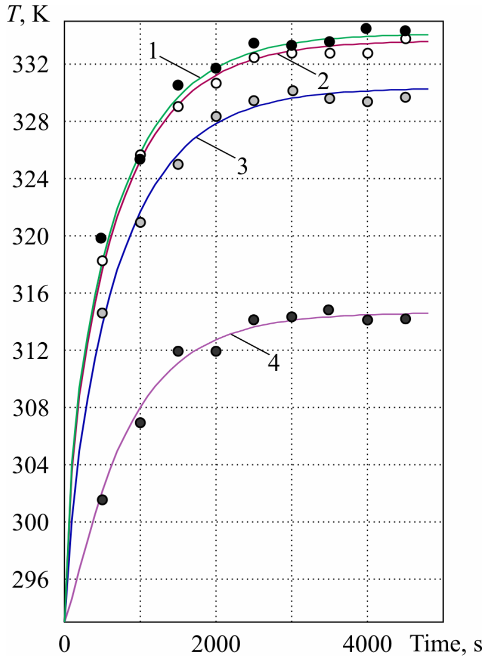

Fig. 8. Temperature variation at different points of electronic board versus time with the power of heat-emitting elements 100 W and thermopile supply current 10 A. 1 – temperature of heat source 1; 2 – temperature of heat source 3; 3 – temperature at x = 125 mm, y = 47.5mm; 4 – temperature at x = 17 mm, y = 14mm.

Figs. 7 and 8 show the plots of temperature variation at control points of electronic board simulator versus time with the use of prototype cooling system. According to the data presented, the use of cooling system reduces the temperature of heat-emitting elements to acceptable values. For the case in Fig. 7 the temperature of heat sources is reduced to 345 K and 344 K, and for Fig. 8 – to 334 K and 333 K. In so doing, temperature background created by heat-emitting elements in the near-by areas of electron board simulator is also reduced.

For the analysis of the energy characteristics of cooling system Figs. 9 and 10 represent temperature variations at control points of electron board simulator versus thermopile supply current and electric energy consumption. According to the data obtained, with increase in current flowing through thermopile, the temperature at all control points is reduced. In so doing, its lowest value for this case at the power of sources of heat 120 W is 344 K, which corresponds to thermopile supply current 9 A. It is obvious that further electric current increase up to the optimal value for this type of TEM (11.3 A) will yield further temperature reduction at control points.

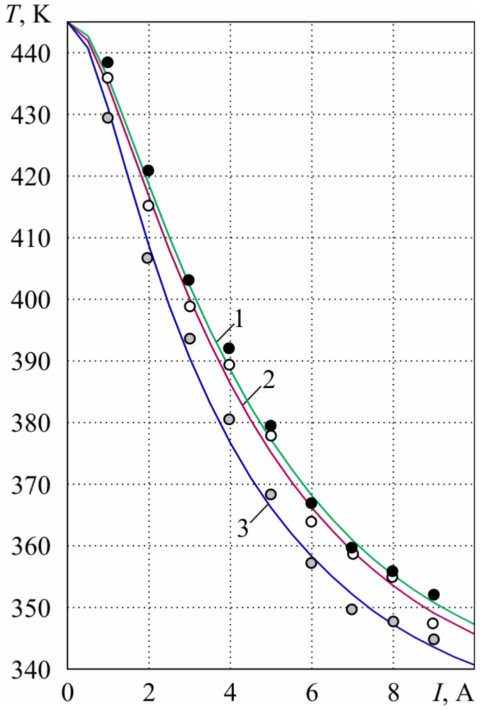

Fig. 9. Temperature variation at different points of electronic board versus thermopile supply current in steady-state mode with the power of heat-emitting elements 120 W. 1 – temperature of heat source 1; 2 – temperature of heat source 3; 3 – temperature at x = 125 mm, y = 47.5 mm.

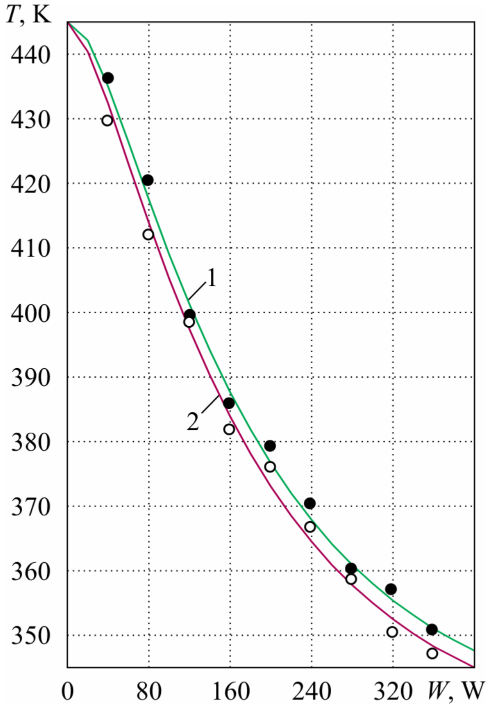

Fig. 10. Temperature variation at different points of electronic board versus thermopile power consumption in steady-state mode with the power of heat-emitting elements 120 W. 1 – temperature of heat source 1; 2 – temperature of heat source 3.

With thermopile current increase, its electric power consumption is increased respectively. For the case represented in Fig. 10 current 9 A is matched by consumed power 360 W.

Fig. 11 gives the data on temperature variation at control points of electronic board simulator with heat removal to the working agent without the use of a thermopile. According to the results, such kind of cooling does not assure the necessary temperature mode of electronic board simulator components. Thus, the temperature of heat-emitting elements is reduced only to the values of 383 K and 385 K, which is insufficient for provision of their temperature working mode.

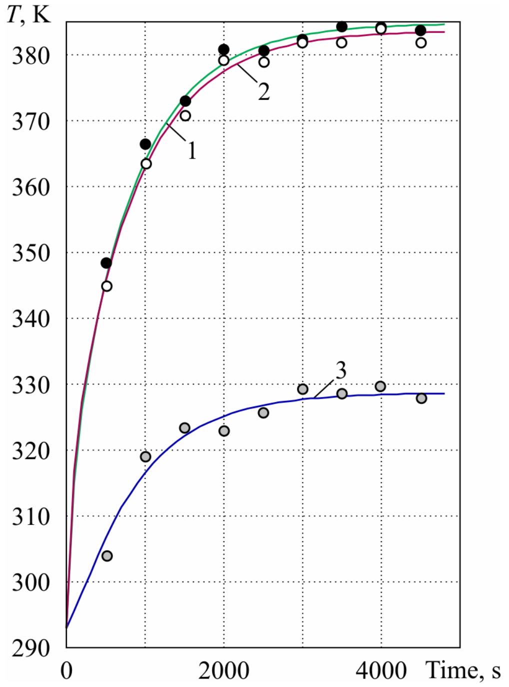

Fig. 11. Temperature variation at different points of electronic board versus time with the power of heat-emitting elements 120 W and heat removal to melting working agent without thermopile. 1 – temperature of heat source 1; 2 – temperature of heat source 3; 3 – temperature at x = 17 mm, y = 14 mm.

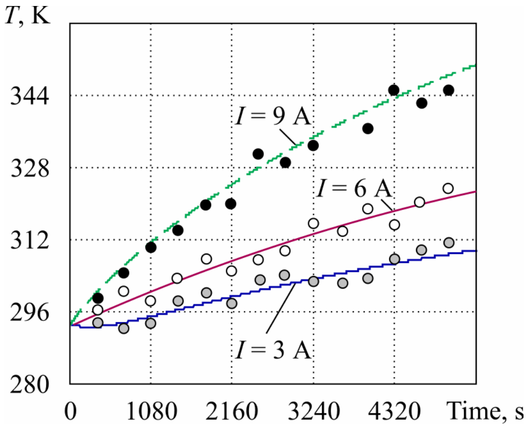

Fig. 12. Time dependence of the cover temperature of working agent container at different thermopile supply currents.

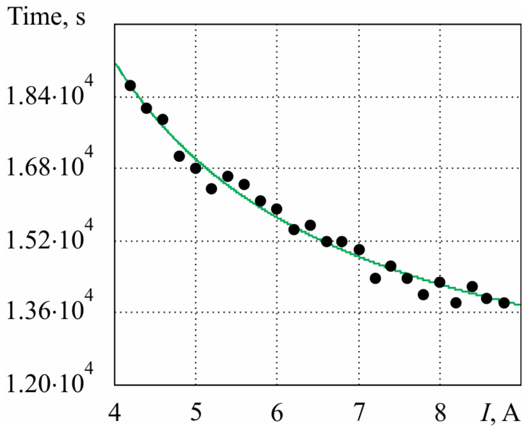

Fig. 13. The time of full melting of the working agent versus thermopile supply current.

Fig. 12 represents experimental time dependences of the cover temperature at working agent melting for different values of thermopile supply current. According to the plots, with a rise in supply current, the amount of heat supplied to the surface of container per unit time (thermal power) is increased, raising the cover temperature. Thus, with the use of paraffin as the working agent, increase in thermopile supply current from 3 to 9 A increases cover temperature by about 40 K in 1.5 h. The agent melting rate is increased respectively. According to Fig. 13 presenting the data on the duration of full melting of agents with different values of thermopile current, increase in electrical current from 4 to 9 A reduces the time of full melting of agents from 5.1 h. to 3.3 h. As a result, it can violate the normal operating mode of electronic board components under respective thermal loads. So, this fact should be taken into account in the design of cooling system.

Based on the above investigations the following conclusions can be made:

1. For efficient cooling of electronic board components, owing to non-uniform distribution of thermal flux on its area, it is advisable to use adequate cooling characterized by non-uniformity of heat pick up along the electronic board area.
2. The above cooling method offers advantages over the usual one, uniform in the energy parameters. According to experimental investigations, the value of power consumption can be reduced by a factor of 1.35 – 1.5. Moreover, the number of thermoelements, heat sink mass, and, respectively, the mass of the entire cooling device can be reduced.
3. With increasing power of electronic board components, the power of thermopiles used for its cooling is increased, which affects the amount of working agent used and must be taken into account in the design of cooling system.

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