LARGE-SIZED THERMOELECTRIC COOLING MODULE WITH HEAT PIPES

L.I. Anatychuk[1], L.N. Vikhor[1], Yu.Ye. Nikolaenko[2], B.M. Rassamakin[3], Yu.Yu. Rozver[1]
([1]Institute of Thermoelectricity, 1, Nauky Str., Chernivtsi, 58029, Ukraine,
[2]The Ministry of Industrial Policy, 3 V. Surikova Str., Kiev, 03035,Ukraine
[3]National Technical University of Ukraine
"Kiev Polytechnic Institute"
Heat-and-power Engineering Department, 6, Politekhnichna Str., Kyiv, 03056, Ukraine)

• *There are presented the experimental development results of large-size thermoelectric cooling module with heat pipes, which is capable to provide a thermal stabilization of electronic components of heightened power. The application of such assemblies of large-size modules and flat heat pipes allows us to meet the challenges of heat removal under increased heat flows and space limitedness for conventional heat-removing heat sinks placing. The construction and manufacturing technique of modules are optimized. The parameters analysis and characteristics of modules with heat pipes in different modes and heat removal conditions are performed. It is shown that it is reasonable to reduce heat pipes thermal resistance to the level of 0.05 K/W for the purpose of cooling efficiency increase.*

Introduction

When designing cooling chambers, air conditioning systems, automotive and household refrigerators, systems for cooling units and radio-electronic equipment devices for specific purposes, the use of thermoelectric modules (TEM) having several well-known advantages (thermostating at temperatures below and above the ambient temperature, ability of transition from cooling to heating modes, absence of moving parts, quiet operation, durability, reliability, etc.) compared with other cooling devices, is considered promising. For example, at the Military Institute of Radio Electronics (Voronezh city, Russian Federation) a new way to manage cooling of electronic equipment with thermal load by means of TEM has been recently proposed, providing for the cold air supply from autonomous TEM directly through flexible insulated ducts to the most critical electronic components and assemblies of radio-electronic equipment [1].

In a number of practical applications, particularly in the thermostats for transportation of biochemical products with up to 3 liters volume, the automotive refrigerators with up to 50 liters volume, in the isothermal bodies with up to 3000 liters volume for cars, in large cooling chambers with up to 20000 liters volume [2], it is desirable to use TEM with maximum possible dimensions of hot and cold plates and with heat transfer enhancement from the plates, which allows to improve their coefficient of performance and cooling capacity. For example, by using TEM with 40 × 40 mm plate dimensions in household refrigerators with heat removal from the hot plate by means of thermosyphon, the coefficient of performance increases by up to 32% [3]. By replacing the ceramic plates with metal ones, the maximum cooling capacity of MD1-125-2.0/1.5-type TEM with 48 × 60 × 3.5 mm dimensions has been increased up to 116.8 W, and the cooling capacity under optimal conditions - up to 100 W [2]. The maximum temperature difference between the hot and cold plates is 71°C. In addition, due to the use of metal plates the output of the regime has been accelerated by 2 – 4 times and the reliability of TEM has been enhanced.

However, at designing TEM with plate dimensions exceeding 48 × 60 mm with the intensification of heat exchange with the plates, one faces a number of structural and technological difficulties, which determine the urgency of the problem of searching for new design solutions, technological approaches, organization of experimental researches and development of calculation methods for such TEM designs[4].

An original decision consisted in developing a new design of TEM containing thermocouples placed between the hot and cold plates, at least one of which is made in the form of a heat pipe [5]. Such TEM design allows to intensify considerably heat exchange with the plates, to develop heat-supplying and heat-dissipating surfaces of the plates and TEM heat sinks, as well as to increase the coefficient of performance and the cooling capacity. The heat pipes for TEM can be metal [6], well as ceramic [7]. Nowadays, the manufacturing technology of the latest ones is being actively developed [8].

The objective of this research is to develop the large-sized thermoelectric cooling module and to determine experimentally its characteristics at operation with flat heat pipes.

Results of designing large-sized module with heat pipes

The theory of designing and computation of optimal characteristics of the thermoelectric modules with the heat pipes is described in detail in [9]. In this paper computer method algorithm, which allows to determine an optimal design and characteristics of the module with the heat pipes, taking into account electrical losses in the contacts of thermoelements, the losses at the thermal resistance of the pipes and insulating plates of the module, is presented.

This method has been used for designing the module structure of traditional materials for thermoelectric coolers based on *Bi-Te* of *n*-and *p*-type conductivity, combined with the heat pipes. The main requirement for the design was that to ensure a high cooling capacity up to 150 W in operating mode with the coefficient of performance of about 0.9 – 1.2. In this case, the heat load on the "cold" heat pipe makes up 150 W, and on the "hot" one – within 300 W.

Special flat aluminum heat pipes filled with ammonia were expected to be used for the connection with the module. The values of the specific thermal resistances for the tubes required for the module designing, have been evaluated theoretically [9]. For the "cold" pipe, the thermal power of which is oriented to 150 W, the value of the specific thermal resistance makes up $r_{ct} = 4$ K·cm^2/W, and for the "hot" pipe with the capacity of heat transfer of 300 W, $r_{ht} = 3$ K·cm^2/W.

As a result of computer simulation, it was found that the initial requirements were provided by the thermoelectric module with the following design:

- the number of thermoelements in the module $n = 508$ pairs of legs;
- the size of the thermoelectric leg: the cross-sectional area is 1.8×1.8 mm^2, the height of the legs is 1.5 mm;
- the legs are located in the area of 10 × 10 cm^2, devided into 16 rows by 8 pairs of legs with the distance between the legs of 0.6 mm;
- electrical connection of the legs is series.

The thermoelectric module insulating plates are made of a conventional material used for thermoelectric cooling modules – alumina of 0.6 mm thickness. The area of the heat pipes must coincide with the area of the module. Therefore, a recommended size of the heat pipe operating surfaces consistent with the module is 10 × 10 cm^2, and the thermal resistance values of the hot and cold heat pipes of this size equal to $R_{ct} = 0.04$ K/W, $R_{ht} = 0.03$ K/W, respectively.

The results of calculation of the characteristics of such large-sized module with the heat pipes at ambient temperature $T_a = 27$°C are presented in Table 1.

The results of the designing privided the basis for an experimental design of the large-sized module with the heat pipes.

Table 1

Calculated characteristics of the module with the heat pipes at ambient temperature $T_a = 27\,°C$

Maximum temperature difference ΔT_{max}, K	58
Maximum cooling capacity Q_{0max}, W	310
Maximum supply current of the module I_{max}, A	11
Maximum voltage U_{max}, V	64
Operating mode with cooling capacity Q_0, W	150
Supply current of the module I, A	5
Voltage U, V	30
Temperature difference ΔT, K	12
Coefficient of performance ε,	1.0
Temperature difference on the "cold" heat pipe, K	6
The temperature difference on the "hot" heat pipe, K	8

Technology features of the large-sized cooling modules

A standard technology of the module assembly in an elastic matrix was used for large-sized module manufacturing. However, large dimensions of the module cause some peculiarities in the technology of its assembly. In order to overcome possible damaging effects of thermal expansion during thermal cycling the hot ceramic plate is divided into four equal sections with 0.6 – 0.7 mm gaps in between. Such structural solution allows to work with heat fluxes on the hot plane up to 650 – 700 W. In this case, the density of heat fluxes in the evaporation zone of the hot heat pipe must not exceed 12 W/cm^2. To avoid the effect of condensed moisture on the module operation, it was sealed by means of a sealant with a low thermal conductivity.

To ensure a high-quality thermal contact between the heat pipes and corresponding planes of TEC, an accurate polishing of its surfaces in order to achieve flatness better than 0.01 mm on the module surface, was conducted.

The appearance of the large-sized module, manufactured by the described technology is shown in Fig. 1.

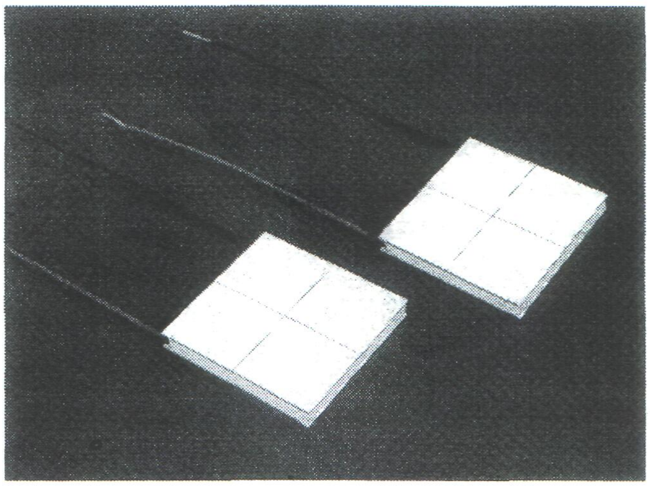

Fig. 1. Appearance of the large-sized thermoelectric cooling modules.

Flat heat pipes have been specifically designed and manufactured for matching with the modules. The design of the heat pipe is a steam chamber with applied special grooves in the evaporation zone to improve heat transfer. The bodies of the heat pipes were made of aluminum alloy. The pipe size to match with the cold surface is oriented to the size of the module. Condensation zone of the hot heat pipe has been increased to accommodate the heat exchanger. Thus, the surface area of the hot heat pipe makes up 10×30 cm^2 with the evaporation zone of 10×10 cm^2 and the condensation zone of 10×20 cm^2.

The attachment of the heat pipes to the working surface of the module was conducted by using special heat conducting glues and clamping devices. The appearance of the module assembly with the heat pipes is shown in Fig. 2.

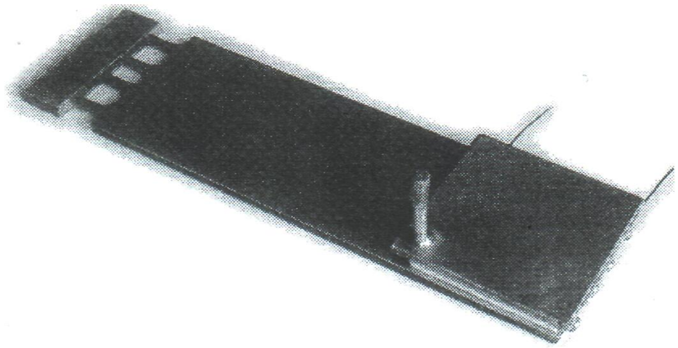

Fig. 2. Assembly of the large-sized thermoelectric cooling module with the heat pipes.

Experimental study of characteristics of the module with the heat pipes

To study the characteristics of the module with the heat pipes a special experimental setup has been developed. The scheme and appearance of the setup are given in Fig. 3.

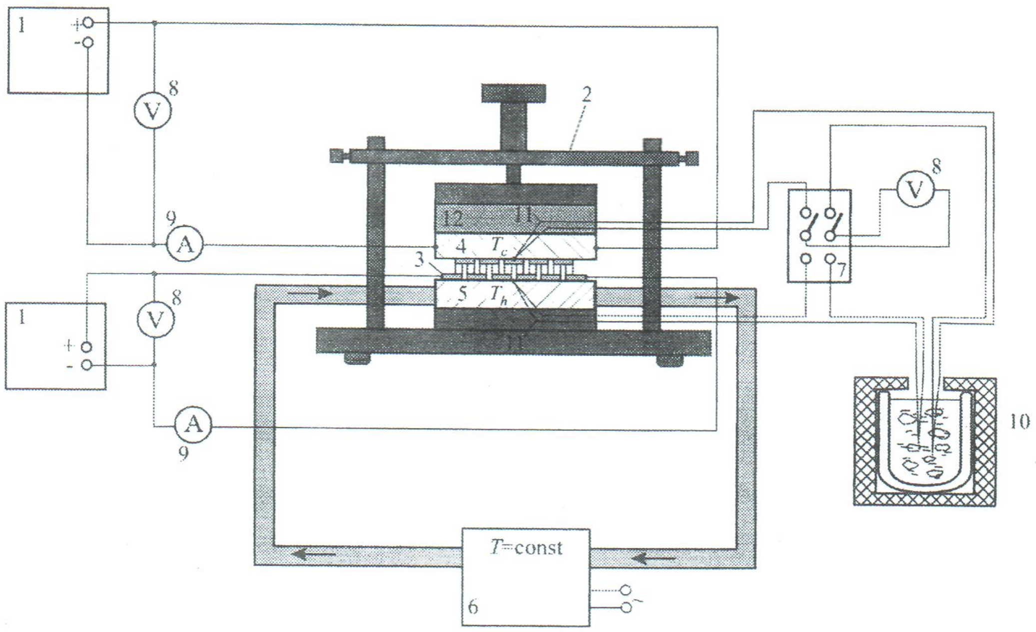

Fig. 3. Experimental setup for investigation of the thermoelectric modules:
1 – power supply unit, 2 – mechanism for clamping, 3 – investigated cooling module (assembly with heat pipes), 4 – electric heater, 5 – heat exchanger, 6 – thermostat, 7 – switch, 8 – voltmeter, 9 – amperemeter, 10 – thermos (water-ice at 0°C), 11 – differential thermocouple, 12 – the heat insulating plastic foam.

The measuring equipment allows to study the parameters and characteristics of the module with the heat pipes in a water- and air flow-cooling conditions.

The results of measuring basic characteristics of the large-sized module with the heat pipes during water-cooling of the "hot" heat pipe are shown in Table 2.

Table 2

Experimental characteristics of the module with the heat pipes at ambient temperature T_a = 27°C.

Maximum temperature difference ΔT_{max}, K	49
Maximum cooling capacity Q_{0max}, W	260
Maximum supply current of the module I_{max}, A	11.5
Maximum voltage U_{max}, V	64
Operating mode with cooling capacity Q_0, W	150
Supply current of the module I, A	5
Voltage U, V	29.6
Temperature difference ΔT, K	3
Coefficient of performance ε	1.01
Temperature difference on the "cold" heat pipe, K	15
Temperature difference on the "hot" heat pipe, K	7.5

Comparison of the results of measuring the characteristics with their theoretically predicted values showed that the temperature drop on the cold heat pipe is higher than a calculated value. Thus, the experimental value of the thermal resistance of this pipe is set too high, which causes inconsistency of experimental characteristics of the module with the heat pipes and its computational indeces.

Conclusions

Possibility of manufacturing the large-size modules combined with the flat heat pipes, was demonstrated in the terms of manufacturing experimental samples and measuring their characteristics. Such modules are capable of maintaining thermal modes of the objects with a high level of heat generation and may find wide application in the air conditioning systems [10, 11], electronic equipment cooling [12] medical boxes for vaccines [13] and in the devices of special assignments.

Application of the assemblies, consisting of large-sized modules and the flat heat pipes, allow to solve the problems of heat removing under conditions of high heat flow and limited space to accommodate conventional heat-removing radiators.

In order to improve the parameters of subsequent cooling assemblies based on the large-sized thermoelectric coolers with the heat pipes it is appropriate to reduce the thermal resistance of the pipes to the level of 0.05 K/W.

References

1. Sanin, V.N., Andrekov I.K., Tsapaev A.P., Kopylova N.A. Thermoelectric cooling of radio-electronic equipment. // Izvestiya VUZov (Proceedings of Higher Education Institutions) – Ser. Radioelectronics. – 2003. – № 9. P. 60 – 65.
2. Thermoelectric modules on metal base and devices based on them. Pribory (Devices). – 2002. – № 11. – P. 16 – 17. (In Russian)
3. Astrain D., Vian J.G., Dominguez V.// Appl. Therm. Eng. – GB. – 2003. – 12. – Vol. 23. – № 17. – S. 2183 – 2200. (Increasing the coefficient of performance of the cooler by optimizing heat dissipation. 2004. – № 5. – P. 99 // Refrigeration engineering. – 2006. – № 3. – P. 63).
4. Thermoelectric cooling systems. Analysis of losses and ways to improve the efficiency. / A.B. Sulin / Refrigeration engineering. – 2009. – № 8. – P. 36 – 39.
5. Patent RU 60271 U1, Russian Federation. HO1L 23/34, Thermoelectric modules / Anatychuk L.I. (UA), Nikolaenko, Yu.Ye. (UA), Vainer A.L. (UA), Nikolaenko, T.Yu (UA) – Application 2005113031/22 of 28.04.2005. Published 10.01.2007, Bulletin № 1. – P. 4.
6. Development, manufacturing and study of heat pipes for the cooling system with large-sized thermoelectric module/ B.M. Rassamakin, S.M. Haymasov, Yu.Ye. Nikolaenko, V.K. Zaripov, Yu.Yu. Rozver // Proceedings of the XI International Scientific and Practical Conference "Modern Information and Electronic Technologies", 24 – 28 May 2010 – Volume II. – Odessa. – P. 33.
7. Patent of Ukraine № 50432, МПК (2009) F28D15/04, F28D15/00, H01L23/34. Device for cooling heat-emitting elements// S.M. Rotner, Yu.Ye. Nikolaenko. – Publ. 16/06/2010. Bulletin. № 11. Application 12548 of 03.12.2009.
8. Nikolaenko Yu.Ye., Rotner S.M. Investigation of capillary structure for flat ceramic heat pipe // Proceedings of the Tenth International Scientific and Practical Conference "Modern Information and Electronic Technologies", May 18 – May 22, 2009 – Volume II. – Odessa. – P. 74.
9. L.I. Anatychuk, L.N. Vikhor, Yu.Ye. Nikolaenko, Yu. Yu. Rozver. Simulation of large-sized thermoelectric cooling module with heat pipes. – J. of Thermoelectricity № 3, 2010. – P. 67 – 72.
10. Patent US6807811. Air conditioner with heat pipe. Jae Hyuk Lee, Oct.26, 2004.
11. Patent KR100861005. Air conditioner comprised thermoelectric module and heat pipe.Vahc Young Woo, Feb.19, 2009.
12. Claude Godet, Christian Tantolin and Mohamed Chaker Zaghdoudi. Use Of Heat Pipe Cooling Systems In The Electronics Industry. Web J. Electronics Cooling. November 1st, 2004.
13. N. Putra. Design, manufacturing and testing of a portable vaccine carrier box employing thermoelectric module and heat pipe. Journal of Medical Engineering; Technology, 2009, Vol. 33, No. 3, P. 232 – 237.

Submitted 30.08.2010.