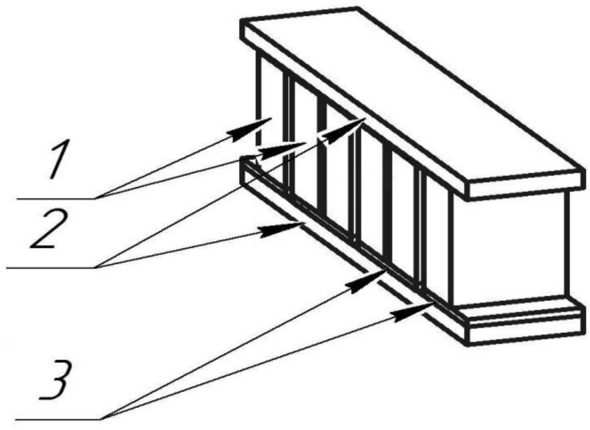


Fig. 1 – Appearance of elementary thermopiles.
1 – thermoelement legs of n- and p-type conductivity,
2 – ceramic plates, 3 – copper connecting plates.

This installation is intended for determination of the electrical and thermal parameters of thermoelectric modules working in generator mode.

Fig. 2 – Installation "Altec-10002".

The operating principle of the installation when used to measure thermopile lies in direct measurement of thermoEMF or voltage at given thermopile load. The thermopile is arranged between heat exchangers that create a regulated steady-state heat flux. The installation also makes it possible to measure current in the load circuit of thermopile, heat flux flowing through the thermopile and to determine its power and efficiency at the installed load.

In laboratory investigations, thermal conditions similar to those set in Performance Specification were reproduced on the measuring installation. The purpose of such investigations was exact assignment of operating ΔT on a thermopile intended for the assembly of annular thermopile breadboard models and determination of their initial characteristics.

Under the elementary thermopile, a heat meter is placed - a device for measuring the heat flux created by the temperature difference between the thermopile working surfaces. The heat meter is a collection of copper rods of the same length and cross-sectional area, in the lateral surfaces of which, at the same distance from the ends, differential thermocouples are mounted. To increase the sensitivity of the heat meter, these thermocouples are interconnected in series. The heat flux that runs along the rods creates a predetermined temperature difference ΔT at the locations of the thermocouples, which is proportional to the value of the heat flux. The proportionality coefficient for each size of the heat meter is calculated and depends on the geometric dimensions and constants of the materials from which it is made. The ends of the rods on both sides are soldered into the heat-leveling copper plates, which are the basis of the heat meter. A junction of a measuring differential thermocouple is integrated on the upper base of the heat meter. The EMF of this thermocouple displays the cold side temperature of the thermopile. The fact that the heat meter is located on the cold side of the thermopile makes it possible to significantly increase the accuracy of heat flux measurement, since the heat loss from the heat meter is minimal.

The hot heat exchanger and heat meter are replaceable and chosen in conformity with the dimensions of thermopiles that are measured.

For more efficient heat transfer between the heat exchangers and thermopiles, the compression force between them must be reliable, optimized and controlled. This is achieved using a lever-weight device, the operation of which is clear from the test bench schematic. The compression force must be limited by the strength of the materials used to create thermopiles (for Bi_2Te_3, the least durable material from which the legs of the module are made, the force should not exceed 20 kg/cm^2).

In the process of measurement, to determine the magnitude of the current, the thermopile should be loaded with external resistance. For this, a rheostat with linear conductors of high resistivity is used in the installation. This form of rheostat is selected for the convenience of accurate selection of load resistance. When measuring the thermal values of error, the losses are mainly determined at the heat spreaders between thermocouples and the objects where they are mounted. The quality of thermal contact also depends on the surface finish of thermopiles. There is also an uncontrolled heat loss from the side surface of the heat meter due to increased convective heat transfer and heat radiation from the surface of the heat meter to the environment, if the cold side temperature of the module is significantly different from room temperature.

At the “Altec-10002” installation, 36 thermopile samples were investigated and selected (with a height of 5.5 mm and a length of 16.5 mm) for the assembly of annular thermopiles for current source breadboard models. Typical parameters and characteristics of thermopiles for an annular thermopile are given in Table 1.

Table 1

Parameters of elementary thermopiles

Module №	R, Ohm	ΔT, °C	U, V	W, W	η, %
1	2	3	4	5	6
1	0.026	270	0.123	0.351	3.78
2	0.025	270	0.130	0.384	3.77
3	0.023	270	0.109	0.327	3.25
4	0.025	270	0.130	0.384	3.93
5	0.025	270	0.118	0.313	3.62
6	0.025	270	0.130	0.357	3.54
7	0.025	270	0.132	0.403	3.94
8	0.024	270	0.132	0.409	3.82
9	0.026	270	0.120	0.306	3.28
10	0.025	270	0.129	0.348	3.49
11	0.024	270	0.128	0.365	3.31

12	0.025	270	0.123	0.326	3.55
13	0.026	270	0.120	0.282	3.39
14	0.024	270	0.125	0.331	3.43
15	0.026	270	0.131	0.347	3.65
16	0.025	270	0.134	0.395	3.81
17	0.025	270	0.127	0.381	3.78
18	0.025	270	0.126	0.359	3.75
19	0.026	270	0.131	0.367	3.69
20	0.025	270	0.122	0.329	3.51
21	0.025	270	0.132	0.383	3.77
22	0.025	270	0.133	0.392	3.72
23	0.025	270	0.128	0.333	3.35
24	0.025	270	0.135	0.398	3.86
25	0.024	270	0.127	0.349	3.59
26	0.028	270	0.110	0.242	2.90
27	0.026	270	0.119	0.292	3.01
28	0.027	270	0.121	0.296	3.39
29	0.024	270	0.107	0.256	3.13
30	0.026	270	0.128	0.346	3.60
31	0.028	270	0.132	0.343	3.61
32	0.027	270	0.128	0.339	3.56
33	0.026	270	0.128	0.358	3.59
34	0.026	270	0.118	0.301	3.43
35	0.025	270	0.123	0.338	3.50
36	0.025	270	0.121	0.296	3.25

where R is thermopile resistance, ΔT is operating temperature difference on the thermopile, U is thermopile generated voltage, W is thermopile power, η is thermopile efficiency. From single-row thermopiles, annular thermopiles were made, the appearance of which is shown in Fig. 3.

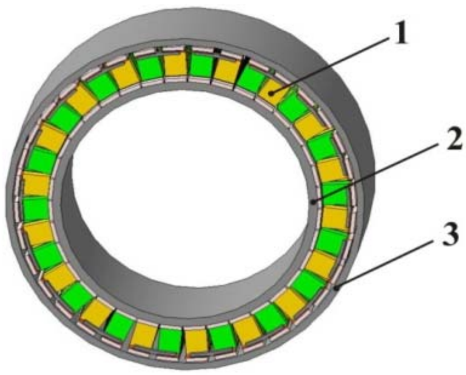


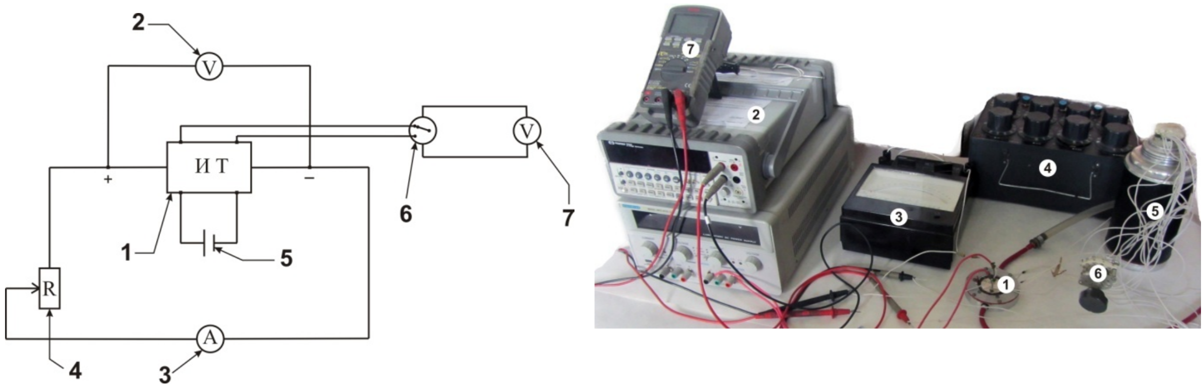
Fig. 3 – Schematic of an annular thermopile:
1 – annular thermopile; 2 – hot heat exchanger ring;
3 – cold heat exchanger ring.

The data presented in Table 1 confirm the efficiency of thermopiles selected for an annular thermopile, as well as the possibility of assuring with their use the initial characteristics of current source breadboard models at the level required by Performance Specification under Contract 3/2019.

Studies of current source breadboard models

Studies of current source breadboard models were performed in accordance with the developed program and the preliminary testing methodology [2]. A heat simulator was used as a heat source. In the course of studies of the electrical parameters of current source breadboard models for compliance with the requirements of the Performance Specification, the dependences of the initial electrical parameters (power P and voltage U) on the temperature gradient ΔT were determined.

Studies of current source breadboard models were performed on the experimental bench the schematic and appearance of which are shown in Fig. 4.

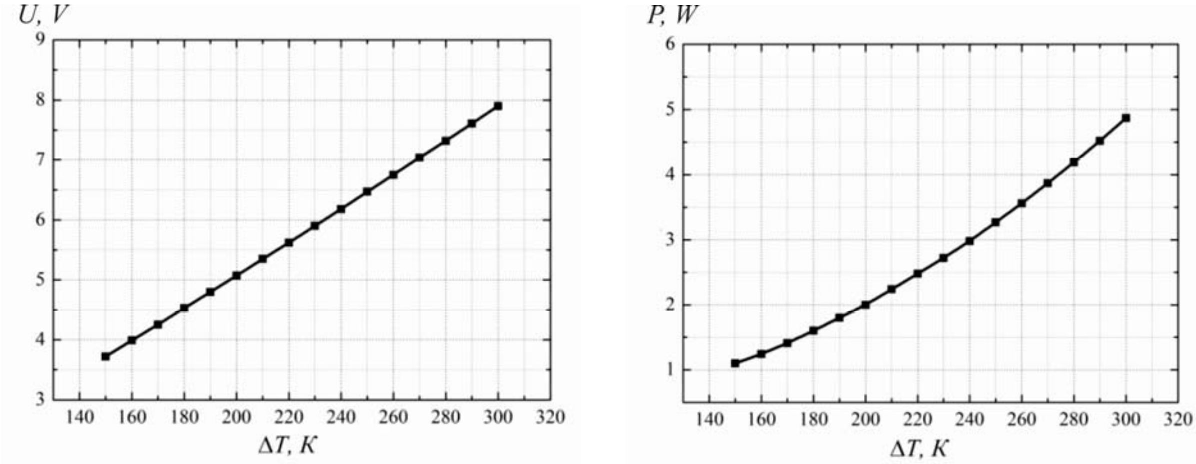


a) *b)*

Fig. 4 – Schematic (a) and appearance (b) of experimental bench for the study of current source breadboard models: 1 – current source breadboard model; 2 – multimeter; 3 – ammeter; 4 – bank of resistors; 5 – power supply; 6 – thermocouple switch; 7 – digital voltmeter; 8 – dewar with ice.

According to the Performance Specification, the output electric power P and the electric voltage U of current source breadboard model should be 2 W and 5 V. Taking into account the electrical parameters given in the Performance Specification, the tests of the current source breadboard model were carried out with an external resistance R = 12.5 Ohm, which was set by the bank of resistors 4. The power of the heat load simulator was increased by the power supply 5. Using a switch 6 and a voltmeter 7, chromel-kopel thermocouples measured the temperatures T_h, T_c of current source heat exchangers with a further determination of the working temperature gradient ΔT on the annular thermopile. In this case, the junction of one thermocouple was placed directly on the hot heat exchanger, and that of the other thermocouple - on the cold heat exchanger. The second junction of the thermocouple was placed in a dewar with ice 8. A multimeter 2 and an ammeter 3 measured the output electric voltage and current strength of a current source breadboard model.

The results of experimental studies of current source breadboard model and the dependences of its electrical parameters on temperature gradient ΔT are given in Fig. 5.



a) *b)*

Fig. 5 – Dependence of electric voltage U (a) and power P (b) of current source breadboard model on the operating temperature gradient ΔT.

From Fig.5 it is seen that with a rise in the temperature gradient *ΔT* on the thermopile, an increase in the electric voltage *U* and power *P* of the breadboard models is observed. In particular, for current source, the required output parameters according to the Performance Specification are already achieved at a working temperature difference of 200 ° C. At the same time, the electric power and voltage of the breadboard model are 2 W and 5 V. With a rise in *ΔT*, the output characteristics of the current source improve, exceeding the values required by the Performance Specification.

However, it should be borne in mind that in the above-mentioned current source studies, a heat load simulator was used, which provides an almost quasi-stationary operating mode of current source, which will not be ensured when using a pyrotechnic element. When using a pyrotechnic element, more stringent current source operating modes will take place, which will require more heat. The estimated time dependence of the heat source thermal power is shown in Fig. 6.

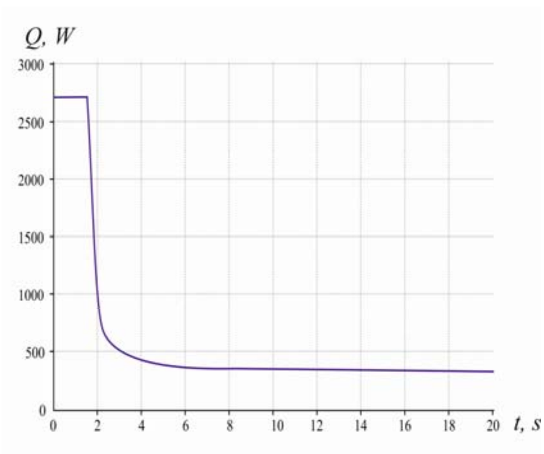


Fig. 6 – Time dependence of thermal power of pyrotechnic heat source.

Conclusion

The results of research confirmed the efficiency of current source breadboard models and the compliance of their electrical parameters with the requirements of the Performance Specification set out in Appendix 1 to Contract 3/2019.

References

1. Anatychuk L.I., Mykytiuk P.D. (2019). Design of an annular thermopile for a single acting current source. *J.Thermoelectricity*, №3, стор. …
2. Program and methods of research on a thermoelectric current source with an annular thermopile. *Contract 3/2019 of 16.04.2019*. Institute of Thermoelectricity.

Submitted 15.052.2019

Анатичук Л.І., *акад. НАН України*[1,2]
Микитюк П.Д. *канд. фіз.-мат. наук*[1,2]
Микитюк О.Ю. *канд. фіз.-мат. наук, доцент*[3]

[1]Інститут термоелектрики НАН і МОН України,
вул. Науки, 1, Чернівці, 58029, Україна,
e-mail: anatych@gmail.com;
[2]Чернівецький національний університет
імені Юрія Федьковича, вул. Коцюбинського 2,
Чернівці, 58012, Україна,
[3]Вищий державний навчальний заклад України
«Буковинський державний медичний університет»,
Театральна площа, 2, Чернівці, 58012, Україна

ДО ПИТАННЯ ВИБОРУ МАТЕРІАЛУ ТЕРМОПАРИ ДЛЯ ТЕРМОПЕРЕТВОРЮВАЧІВ МЕТРОЛОГІЧНОГО ПРИЗНАЧЕННЯ

Наведено результати досліджень термоелектричного джерела струму одноразової дії з кільцевою термоелектричною батареєю. Результати досліджень підтвердили працездатність макетних зразків ДС з кільцевою термобатареєю (ТЕБ) і відповідність їх електричних параметрів вимогам технічного завдання за договором 3/2019. Бібл. 2, рис. 6, табл. 1.
Ключові слова: термоелектрична батарея, джерело струму, номінальна напруга, вихідна потужність.

Анатычук Л.И., *акад. НАН Украины*[1,2]
Микитюк П.Д. *канд. физ.-мат. наук*[1,2]
Микитюк О.Ю. *канд. физ.– мат. наук, доцент*[3]

[1]Институт термоэлектричества НАН и МОН Украины,
ул. Науки, 1, Черновцы, 58029, Украина,
e-mail: anatych@gmail.com;

[2]Черновицкий национальный университет
имени Юрия Федьковича, ул. Коцюбинского 2,
Черновцы, 58012, Украина
[3]Высшее государственное учебное заведение Украины
«Буковинский государственный медицинский университет»,
Театральная площадь, 2, Черновцы, 58002, Украина

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ТЕРМОЭЛЕКТРИЧЕСКОГО ИСТОЧНИКА ТОКА С КОЛЬЦЕВОЙ ТЕРМОЭЛЕКТРИЧЕСКОЙ БАТАРЕЕЙ

Приведены результаты исследований термоэлектрического источника тока одноразового действия с кольцевой термоэлектрической батареей. Результаты исследований подтвердили работоспособность макетных образцов ИТс кольцевой термобатареей (ТЭБ) и соответствие их электрических параметров требованиям технического задания по договору 3/2019. Библ. 2, рис. 6, табл. 1.

Ключевые слова*:* термоэлектрическая батарея, источник тока, напряжение, выходная мощность.

References

1. Anatychuk L.I., Mykytiuk P.D. (2019). Design of an annular thermopile for a single acting current source. *J.Thermoelectricity*, №3, стор. …
2. Program and methods of research on a thermoelectric current source with an annular thermopile. *Contract 3/2019 of 16.04.2019*. Institute of Thermoelectricity.

Submitted 15.05.2019

A.V. Prybyla

A.V. Prybyla, *cand. phys. - math. sciences*[1,2]

[1]Institute of Thermoelectricity
of the NAS and MES of Ukraine,
e-mail: anatych@gmail.com
1, Nauky str., Chernivtsi, 58029, Ukraine;
[2]Yu.Fedkovych Chernivtsi National University,
2, Kotsiubynskyi str., Chernivtsi, 58000, Ukraine

DESIGN OF A THERMOELECTRIC COOLING MODULE FOR AN X-RAY DETECTOR

The paper presents the results of designing a thermoelectric multistage thermoelectric cooling module for X-ray detectors. The structure of a thermoelectric cooler as part of an X-ray detector is developed and the possibilities of its practical use are analyzed. Bibl. 12, Fig. 2.
Key words: computer design, thermoelectric cooling, X-ray detector.

Introduction

General characterization of the problem. X-ray methods are widely used for non-destructive microanalytical studies of the structure and composition of materials with high spatial resolution [1]. The current state of nuclear microanalysis methods using focused beams of MeV energy ions with high monoenergeticity ($\Delta E/E$=10^{-5}) allows spatial resolution on the surface of up to 100 nanometers and up to 10 nanometers in the sample thickness. Further enhancement of the resolution substantially depends on the improvement of the analytical characteristics of semiconductor detectors, as well as on the use of wide-aperture position-sensitive radiation detectors of new types [2].

To increase the resolution of x-ray detectors, it is important to solve the problem of ensuring the optimal temperature of their operation [3-9].

It is solved by using semiconductor thermoelectric cooling modules [5-9] to provide the required cooling depth in the minimum working volume of the detector. Thus, single-stage thermoelectric modules are used for shallow cooling (to 250 K). Two-stage thermoelectric cooling modules are used for cooling sensors to operating temperature of 230 K, three-stage modules - to temperature of 210 K, four and five-stage modules – to temperatures below 190 K [10].

Therefore, the purpose of this work is to analyze the capabilities of thermoelectricity for cooling X-ray detectors and to design a multi-stage thermoelectric cooler for X-ray detectors.

Physical model

For the calculations, we used the physical model of a thermoelectric cooler as part of an X-ray detector presented in Fig. 1. It consists of a housing 2 with a beryllium window 1 through which radiation enters the X-ray detector 3. The required temperature and thermal conditions on the surface of the X-ray detector are provided by a multi-stage thermoelectric cooler with an electric power W consisting of n- and p-type thermoelectric material legs 8, electrically conductive interconnect plates 9, ceramic electrical insulation plates 7. A vacuum is created inside the detector housing 4 to reduce heat loss. The heat flow is removed from the thermoelectric cooler through the base of detector housing 5 and its fixture 6.