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Розглянуто вплив геометрії гілок термоелементів на основні параметри і показники надійності однокаскадного термоелектричного охолоджуючого пристрою для різних перепадів температури при тепловому навантаженні 2,0 Вт для характерних режимів (Q_0/I)max і (Q_0/I^2)max. Показано, що для різних перепадів температури при зменшенні відношення висоти гілки термоелемента до площини її поперечного зрізу інтенсивність відмов зменшується

Ключеві слова: термоелектричний охолоджуючій пристрій, показники надійності, перепад температури, геометрія термоелементів

Рассмотрено влияние ветвей термоэлементов на основные параметры и показатели надежности однокаскадного термоэлектрического охлаждающего устройства для различных перепадов температуры при тепловой нагрузке 2,0 Вт для характерных режимов $(Q_0/I)_{max}$ и $(Q_0/I^2)_{max}$. Показано, что для различных перепадов температуры при уменьшении отношения высоты ветви термоэлемента к площади ее поперечного сечения интенсивность отказов уменьшается

Ключевые слова: термоэлектрические охлаждающее устройство, показатели надежности, перепад температуры, геометрия термоэлементов

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ANALYSIS OF THE MODEL OF INTERDEPENDENCE OF THERMOELEMENT BRANCH GEOMETRY AND RELIABILITY INDICATORS OF THE SINGLE-STAGE COOLER

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1. Introduction

The problem of improving reliability of thermoelectric coolers used in electronics thermal condition control systems remains the pressing problem because of permanently toughening requirements to the present-day land-based and on-board equipment. Improvement of reliability indicators of thermoelectric coolers is realized according to various principles at various steps:

– in design engineering: according to parametric and design approaches;

– in production: by technology development;

– in operation: by selection of operation conditions.

2. Literature review and problem statement

Considerable attention to analysis of the problems of reliability of thermoelectric coolers [1, 2] is paid because viability of the entire system is directly determined by the working capacity of critical heat-loaded elements. The parametric approach is based on choosing thermoelectric materials [3, 4] with parameters connected with the thermoelectric device (TED) reliability indicators [5, 6]. Current mode choice determines energy-related operation conditions [7] which are directly related with the cooler reliability indicators [8]. When the design approach is analyzed, the qualitative aspect of ensuring specified levels of reliability of thermoelectric coolers is only considered [9, 10]. At the same time, the model of interrelation between the basic parameters and the reliability indicators was established and developed [11]. This enables a comprehensive estimation of thermoelement branch geometry effect on the single-stage TED reliability for various operation conditions. Potentially, this approach enables choice of optimal thermoelement branch geometry. At the same time, failure rate must decrease and probability of failure-free operation of the cooler must increase taking into account restrictive requirements to size, weight and power consumption. Obtaining of a quantitative relation between thermoelement geometry and reliability indicators of thermoelectric coolers involves studies for various temperature gradients and operation conditions.

3. The aim and tasks of the study

The aim of this work is to find design approaches to the improvement of reliability indicators through selection of an optimal geometry of thermocouple branches for different operation conditions.

To achieve this objective, solution of the following tasks is necessary:

– develop a reliability-oriented model linking reliability indicators with the geometry of thermoelement branches for various temperature gradients and the fixed thermal load for operation modes $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$;

– determine the possibility of improvement of reliability indicators of the single- stage TEU in modes $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$ by selecting thermocouple branch geometry.

4. Development and analysis of the model of interrelation between reliability indicators and design and energy parameters in modes $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$

4. 1. The model of interrelation between reliability indicators of the single-stage TED and thermoelement branch geometry

The ratio of thermoelement branch height l to cross-sectional area S called as thermoelement geometry is directly connected with the cooler reliability indicators. By varying operation current value, it is possible to ensure the cooler operation in all operation modes from the maximum cooling power Q_{0max} to the minimum failure rate λ_{min}. Consider the effect of geometry in the most frequently used modes $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$ for various temperature gradients $\Delta T=0\div60$ K for a given heat load $Q_0=2{,}0$ W.

To solve this problem, use the earlier developed relationships [11].

The cooling power of the thermoelectric cooling unit (TEU) can be represented as:

$$Q_0 = nI_{max}^2R\left(2B-B^2-\Theta\right) = n\gamma\left(2B-B^2-\Theta\right), \qquad (1)$$

where n is the number of thermocouples; $I_{max}=\bar{e}T_0/R$ is the maximum operating current, A; $R=\dfrac{l}{\bar{\sigma}S}$ is electrical resistance of the thermoelement branch, Ohm; $\bar{e}$, $\bar{\sigma}$ are averaged values of coefficient of thermal electromotive force, B/K and electrical conductivity, Cm/cm of thermoelement branch respectively; T_0 is temperature of the heat-absorbing junction, K; $B=I/I_{max}$ is the relative operating current, relative units; I is the value of operation current, A;

$$\Theta = \frac{\Delta T}{\Delta T_{max}} = \frac{T-T_0}{\Delta T_{max}}$$

is relative temperature gradient, relative units; T is the temperature of the heat-generating junction, K;

$$\Delta T_{max} = 0{,}5\bar{z}\,T_0^2$$

is the maximum temperature gradient K; $\bar{z}$ is the averaged thermoelectric efficiency of thermoelement branch, 1/K;

$$\gamma = I_{max}^2R = \bar{e}^2\bar{\sigma}T_0^2\frac{S}{l}$$

is the maximum thermoelectric cooling power, W.

The TEU power consumption can be expressed as:

$$W = 2n\gamma B\left(B+\frac{\Delta T_{max}}{T_0}\Theta\right). \qquad (2)$$

The TEU refrigeration coefficient can be written down as:

$$E = \frac{Q_0}{W} = \frac{2B-B^2-\Theta}{2B\left(B+\dfrac{\Delta T_{max}}{T_0}\Theta\right)}. \qquad (3)$$

Relative failure rate can be expressed as:

$$\frac{\lambda}{\lambda_0} = \frac{nB^2\left(\Theta+C_1\right)\left(B+\dfrac{\Delta T_{max}}{T_0}\Theta\right)^2}{\left(1+\dfrac{\Delta T_{max}}{T_0}\Theta\right)^2}K_T, \qquad (4)$$

where

$$C_1 = \frac{Q_0}{nI_{max}^2R} = \frac{Q_0}{n\gamma}$$

is the relative heat load, relative units; K_T is the significance coefficient depending on the temperature [11].

The probability of failure-free operation of TEU can be determined by the formula:

$$P=\exp(-\lambda t), \qquad (5)$$

where t is the assigned resource, hr.

4. 2. Analysis of the simulation results

Calculation of the basic parameters and reliability indicators of the single-stage TEU for different ratios l/S = var in modes $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$ was conducted with the following starting data:

– heat load $Q_0=2$ W;
– temperature of the heat-generating junction T=300 K;
– temperature gradient $\Delta T=10\div60$ K;
– $\lambda_0=3\cdot10^{-8}$ 1/hr, $t=10^4$ hr.

Calculation results are given in Tables 1, 2.

At an equal heat load Q_0 and temperature gradient ΔT:

$$n\gamma=\text{const} \qquad (6)$$

for various thermoelement branch geometries l/S.

1) Mode $(Q_0/I)_{max}$.

Analysis of the calculated basic parameters and reliability indicators has shown that with reduction in the ratio l/S at a given temperature gradient ΔT and heat load Q_0 in the mode $(Q_0/I)_{max}$:

- maximum cooling power γ increases (Fig. 1);
- operating current I increases (Fig. 1);
- the number n of thermoelements decreases (Fig 2);
- the voltage U drop decreases (Fig 2);
- the failure rate λ decreases (Fig. 3);
- the failure-free operation probability P increases (Fig. 3)

at constant values of power consumption W and refrigeration coefficient E.

Table 1

Calculation data for basic parameters and reliability indicators of the single-stage TEU for various temperature gradients ΔT at $T=300$ K, heat load $Q_0=2.0$ W in $(Q_0/I)_{max}$ mode

l/S	γ, W	n, pcs.	$R\times10^3$, Ohm	I_{max}, A	I, A	U, V	λ/λ_0	$\lambda\times10^8$, 1/hr	P	S=a×b, mm
ΔT=10 K $B=0.316$; $\Theta=0.1$; $K_T=1.007$; $\Delta T_{max}=101$ K; $\Delta T_{max}/T_0=0.35$; W=1.03 W; E=1,94 $\bar{e}=1.99$ V/K; $\bar{\sigma}=920$ Cm/cm; $\bar{æ}=15.2$ W/(cm·K) $\bar{z}=2.4\cdot10^{-3}$ 1/K										
40.0	0.077	60.2	43.5	1.33	0.42	2.45	0.37	1.11	0.999889	1.0×1,0
20.0	0.154	30.2	21.7	2.66	0.84	1.23	0.185	0.555	0.999944	1.4×1,4
10.0	0.308	15.1	10.9	5.32	1.68	0.61	0.093	0.28	0,99997	2,0×2,0
4.5	0.577	6.8	4.89	11.8	3.73	0.28	0.042	0.125	0.999987	3.0×3,0
3.25	0.938	4.94	3.53	16.3	5.17	0,20	0.031	0.0915	0.9999909	3.5×3,5
2.0	1.54	3.02	2.17	26.6	8.4	0.123	0.019	0.057	0.9999943	4.5×4,5
ΔT=20 K $B=0.463$; $\Theta=0.214$; $K_T=1.011$; $\Delta T_{max}=93.3$ K; $\Delta T_{max}/T_0=0.33$; W=2.0 W; E=1.0; $\bar{e}=1.97$ B/K; $\bar{\sigma}=940$ Cm/cm; $\bar{æ}=15.3$ W/(cm·K) $\bar{z}=2.38\cdot10^{-3}$ 1/K										
40.0	0.0715	55.8	42.6	1.30	0.60	3.33	1.35	4.0	0.99960	1.0×1,0
20.0	0.143	28.2	2.,3	2.60	1.2	1.67	1.08	3.2	0.99968	1.4×1,4
10.0	0.286	14.1	1.,64	5.2	2.4	0.83	0.54	1.62	0.99984	2.0×2,0
4.5	0.676	5.96	4.79	11.5	5.3	0.38	0.23	0.684	0.999932	3.0×3,0
3.25	0.880	4.57	3.46	15.9	7.4	0.27	0.175	0.525	0.999948	3.5×3,5
2.0	1.43	2.82	2.13	25.9	12.0	0.17	0.11	0.32	0.999968	4.5×4,5
1.0	2.86	1.41	1.06	52.0	24.1	0.083	0.055	0.165	0.999984	6.3×6,3
ΔT=40 K $B=0.71$; $\Theta=0.5$; $K_T=1.022$; $\Delta T_{max}=79.8$ K; $\Delta T_{max}/T_0=0.31$; W=5.9 W; E=0.34; $\bar{e}=1{,}94$ B/K; $\bar{\sigma}=980$ Cm/cm; $\bar{æ}=15{,}6$ W/(cm·K) $\bar{z}=2{,}37\cdot10^{-3}$ 1/K										
40.0	0.0625	76.7	40.8	1.24	0.88	6.70	20.4	61.2	0.9939	1.0×1,0
20.0	0.125	38.5	20.4	2.47	1.75	3.4	10.2	30.6	0.99694	1.4×1,4
10.0	0.250	19.3	10.2	4.95	3.50	1.7	5.1	15.4	0.9985	2.0×2,0
4.5	0.577	8.7	4.6	11.0	7.80	0.76	2.3	6.9	0.99931	3.0×3,0
3.25	0.767	6.3	3.3	15.2	10.8	0.55	1.66	5.0	0.99950	3.5×3,5
2.0	1.220	3.9	2.0	24.7	17.5	0.34	1.02	3.0	0.99969	4.5×4,5
ΔT=60 K $B=0.949$; $\Theta=0.9$; $K_T=1.035$; $\Delta T_{max}=66.8$ K; $\Delta T_{max}/T_0=0.28$; W=47 W; E=0.0426; $\bar{e}=1.89$ V/K; $\bar{\sigma}=1030$ Cm/cm; $\bar{æ}=15.9$ Вт/(cm·K) $\bar{z}=2.32\cdot10^{-3}$ 1/K										
40.0	0.053	389	38.8	1.17	1.10	42.7	332.6	997.8	0.9050	1.0×1,0
20.0	0.106	194.5	19.4	2.34	2.2	21.2	166.3	500.0	0.9512	1.4×1,4
10.0	0.212	97.3	9.7	4.67	4.4	10.6	83.2	250.0	0.9753	2.0×2,0
4.5	0.471	43.8	4.4	10.4	9.9	4.8	37.5	112.4	0.9888	3.0×3,0
3.25	0.652	31.6	3.2	14.4	13.7	3.4	27.0	81.0	0.9919	3.5×3,5
2.0	1.06	19.5	1.9	23.4	22.2	2.1	16.6	50.	0.9950	4.5×4,5

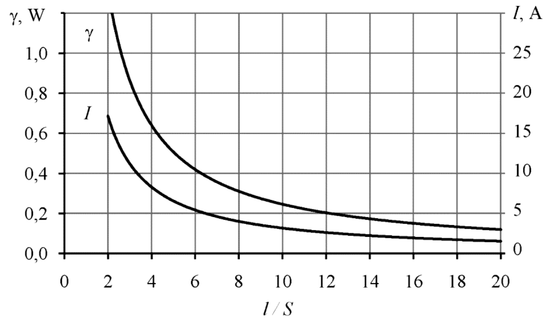

Fig. 1. Dependence of the single-stage TEU parameters γ, I on the value of relation l/s at T=300 K, ΔT=40 K and Q_0=2.0 W in the mode $(Q_0/I)_{max}$)

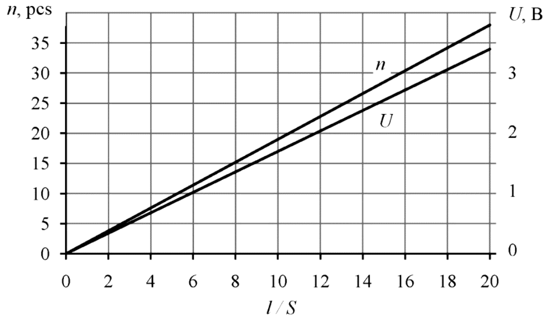

Fig. 2. Dependence of parameters n, U of the single-stage TEU on the value of relation l/s at T=300 K, ΔT=40 K and Q_0=2.0 W in the mode $(Q_0/I)_{max}$

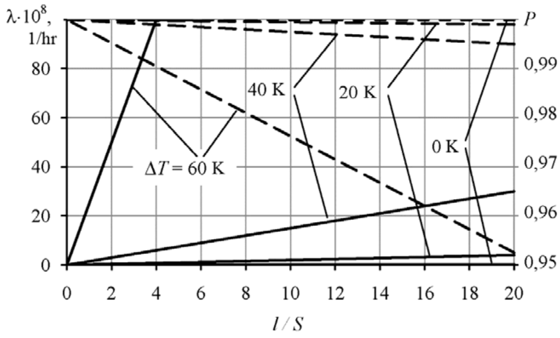

Fig. 3. Dependence of the failure rate λ (solid lines) and the probability P of failure-free operation (dotted lines) of the single-stage TEU on the value of relation l/s at T=300 K, Q_0=2.0 W and various values of ΔT in the mode $(Q_0/I)_{max}$

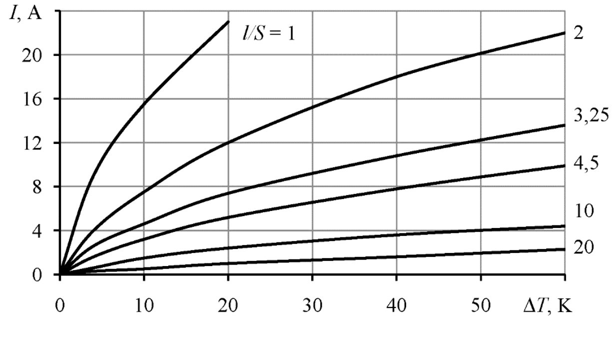

Fig. 4. Dependence of the operation current I of the single-stage TEU on the temperature variation ΔT at T=300 K, Q_0=2.0 W and various values of relation l/s in the mode $(Q_0/I)_{max}$

With the growth of the temperature gradient ΔT at a given heat load Q0 for different values of l/S:

– the maximum thermoelectric cooling power γ decreases;

– the value of the operation current I increases (Fig. 4);

– functional dependence of thermoelement number n in the TEU on ΔT is minimal (Fig. 5);

– failure rate λ increases (Fig. 6);

– probability P of failure-free operation decreases (Fig. 7).

Operation current I increases with reduction of ratio l/S (Fig. 8).

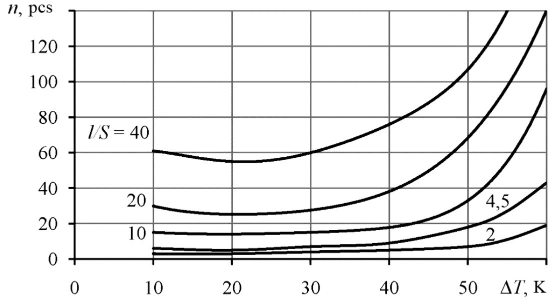

Fig. 5. Dependence of the number n of thermoelements in the single-stage TEU on the temperature variation ΔT at T=300 K, Q_0=2.0 W and various values of relation l/s in the mode $(Q_0/I)_{max}$

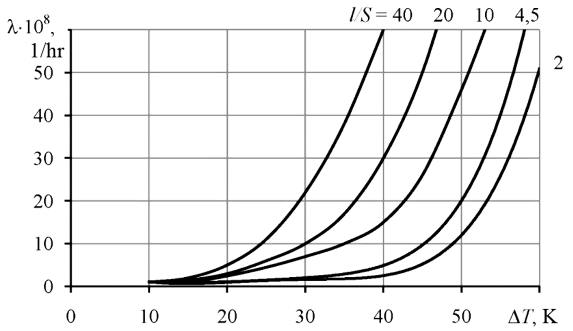

Fig. 6. Dependence of failure rate λ of the single-stage TEU on temperature variation ΔT at T=300 K, Q_0=2.0 W and various relations l/s in the mode $(Q_0/I)_{max}$

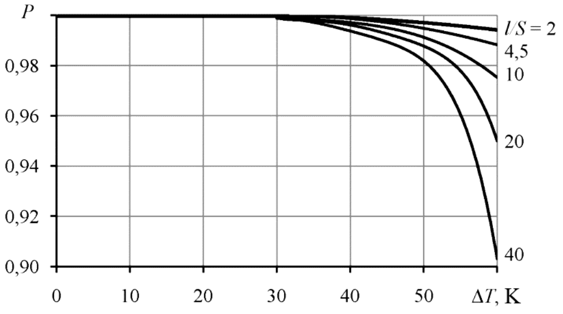

Fig. 7. Dependence of the probability P of failure-free operation of the single-stage TEU on the temperature variation ΔT at T=300 K, Q_0=2.0 W and various values of ratio l/s in the mode $(Q_0/I)_{max}$

Note that the reduction in ratio l/S from 20 to 10 for the mode $(Q_0/I)_{max}$ at ΔT=40 K and Q_0=2.0 W makes it possible to reduce failure ratio λ by 50 % and therefore increase the probability P of failure-free operation. Besides, the value of the operation current I increases from 1.75 to 3.5 A, power consumption W and refrigeration coefficient E remain constant (W=5.9 W and E=0.34) and the number of thermoelements halves.

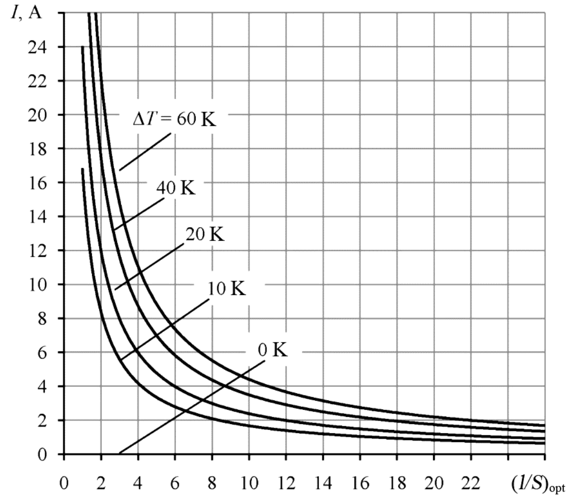

Fig. 8. Dependence of the operation current I and the optimum value $(l/s)_{opt}$ of the single-stage TEU on the temperature gradient ΔT at T=300 K, Q_0=2.0 W and various values of ΔT in the mode $(Q_0/I)_{max}$

2) Mode $(Q_0/I^2)_{max}$.

Analysis of the calculated values of the basic parameters and reliability indicators has shown that with reduction in the ratio l/S at a given temperature variation ΔT and heat load Q_0 in the mode $(Q_0/I^2)_{max}$:

– the maximum cooling power γ increases (Fig. 9);

– the value of the operation current I increases (Fig. 9);

– the number of thermoelements n decreases (Fig. 10);

– the voltage drop U decreases (Fig. 10);

– the failure rate λ decreases (Fig. 11);

– the probability P of failure-free operation increases (Fig. 11)at constant values of power consumption W and refrigeration factor E.

With the growth of temperature gradient ΔT at a given heat load Q_0 for various values of l/S:

– the maximum thermoelectric cooling power γ decreases;

– the value of the operation current I increases (Fig. 12).

– the functional dependence of the number of thermoelements n in the TEU on ΔT has a pronounced minimum (Fig. 13) which can be explained by the growth of the cooling power per one thermoelement (Q_0/n) for ΔT_{opt} at the point of minimum;

– failure rate λ increases (Fig. 14);

– probability P of failure-free operation decreases (Fig. 15).

Table 2

Calculation data of the basic parameters and reliability indicators of the single-stage TEU for various temperature gradients ΔT at T=300 K, heat load Q_0=2.0 W in the mode $(Q_0/I^2)_{max}$

l/S	γ, W	n, pcs.	R×10³, Ohm	I_{max}, A	I, A	U, V	λ/λ_0	λ×10⁸, 1/hr	P	S=a×b, mm
1	2	3	4	5	6	7	8	9	10	11
ΔT=10 K B=0.1; Θ=0.1; K_T=1.007; ΔT_{max}=101 K; $\Delta T_{max}/T_0$=0.35; W=0.6 W; E=3.33; $\bar{e}$=1.99 B/K; $\bar{\sigma}$=920 Cm/cm; $\bar{æ}$=15.2 W/(cm·K) $\bar{z}=2.4\cdot10^{-3}$ 1/K										
40.0	0.077	289.0	43.5	1.33	0.133	4.51	0.0094	0.028	0.9999972	1.0×1.0
20.0	0.154	144.7	21.7	2.66	0.266	2.26	0.0047	0.0141	0.9999986	1.4×1.4
10.0	0.308	72.2	10.9	5.32	0.532	1.13	0.00235	0.0070	0.99999997	2.0×2.0
4.5	0.682	32.6	4.9	11.8	1.18	0.51	0.00106	0.0032	0.99999987	3.0×3.0
2.0	1.54	14.5	2.17	26.6	2.66	0.23	0.00047	0.00141	0.99999986	4.5×4.5
ΔT=20 K B=0.214; Θ=0.214; K_T=1.011; ΔT_{max}=93.3 K; $\Delta T_{max}/T_0$=0.33; W=1.45 W; E=1.38; $\bar{e}$=1.97 B/K; $\bar{\sigma}$=940 Cm/cm; $\bar{æ}$=15.3 W/(cm·K) $\bar{z}=2.38\cdot10^{-3}$ 1/K										
40.0	0.0715	166.4	42.6	1.30	0.28	5.3	0.21	0.63	0.999937	1.0×1.0
20.0	0.143	83.2	21.3	2.60	0.56	2.64	0.104	0.31	0.99997	1.4×1.4
10.0	0.286	41.6	10.64	5.2	1.11	1.31	0.052	0.156	0.999984	2.0×2.0
4.5	0.676	17.6	4.79	11.5	2.46	0.59	0.022	0.066	0.9999934	3.0×3.0
2.0	1.43	8.3	2.13	25.9	5.54	0.26	0.010	0.03	0.999997	4.5×4.5
ΔT=30 K B=0.346; Θ=0.346; K_T=1.016; ΔT_{max}=86.8 K; $\Delta T_{max}/T_0$=0.32; W=2.8 W; E=0.71; $\bar{e}$=1.96 B/K; $\bar{\sigma}$=970 Cm/cm; $\bar{æ}$=15.5 W/(cm·K) $\bar{z}=2.38\cdot10^{-3}$ 1/K										
40.0	0.0675	131.1	41.2	1.28	0.443	6.32	1.545	4.63	0.999537	1.0×1.0
20.0	0.136	65.6	20.6	2.57	0.89	3.15	0.77	2.31	0.99977	1.4×1.4
10.0	0.272	32.8	10.3	5.14	1.78	1.57	0.385	1.155	0.99988	2.0×2.0
4.5	0.603	14.7	4.64	11.4	3.94	0.71	0.173	0.518	0.999948	3.0×3.0
2.0	1.36	6.5	2.0	25.7	8.89	0.315	0.0765	0.229	0.9999774	4.5×4.5

Continuation ofTable 2

1	2	3	4	5	6	7	8	9	10	11
ΔT=40 K B=0.5; Θ=0.5; K_T 1.022; ΔT_{max}=79.8 K; $\Delta T_{max}/T_0$=0.31; W=5.24 W; E=0.38; $\bar{e}$=1.94 B/K; $\bar{\sigma}$=980 Cm/cm; $\bar{æ}$=15.6 W/(cm·K) $\bar{z}$=2.37·10^{-3} 1/K										
40.0	0.0625	128.0	40.8	1.24	0.62	8.4	7.98	23.6	0.9976	1.0×1.0
20.0	0.125	64.0	20.4	2.47	1.24	4.22	3.94	11.8	0.9988	1.4×1.4
10.0	0.25	32.1	10.2	4.95	2.48	2.10	1.98	5.94	0.99941	2.0×2.0
4.5	0.557	14.4	4.6	11.0	5.50	0.95	0.89	2.67	0.999973	3.0×3.0
2.0	1.25	6.4	2.04	24.7	12.4	0.42	0.40	1.20	0.99988	4.5×4.5
ΔT=60 K B=0.9; Θ=0.9; K_T=1.035; ΔT_{max}=66.8 K; $\Delta T_{max}/T_0$=0.28; W=46.1 W; E=0.043; $\bar{e}$=1.89 B/K; $\bar{\sigma}$=1030 Cm/cm; $\bar{æ}$=15.9 W/(cm·K) $\bar{z}$=2.32·10^{-3} 1/K										
40.0	0.053	420	38.8	1.17	1.05	39.0	294.6	883.8	0.9154	1.0×1.0
20.0	0.106	210	19.4	2.34	2.11	19.7	147.3	442.0	0.9568	1.4×1.4
10.0	0.212	105	9.7	4.67	4.20	11.0	73.7	221.1	0.9781	2.0×2.0
4.5	0.471	47.2	4.4	10.4	9.4	4.9	33.2	99.6	0.9901	3.0×3.0
2.0	1.06	21.0	1.9	23.4	21.1	2.2	14.8	44.4	0.9956	4.5×4.5

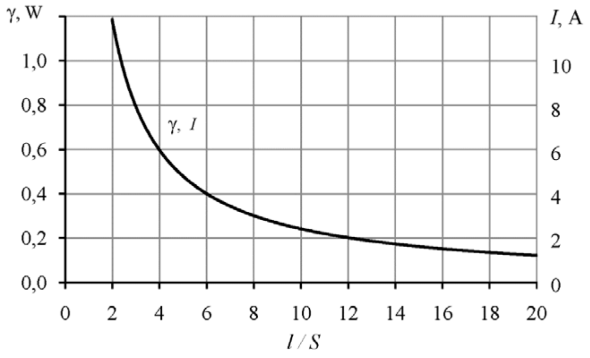

Fig. 9. Dependence of parameters γ, I of the single-stage TEU on the value of ratio l/s at T=300 K. ΔT=40 K and Q_0=2.0 W in the mode $Q_0/I^2)_{max}$

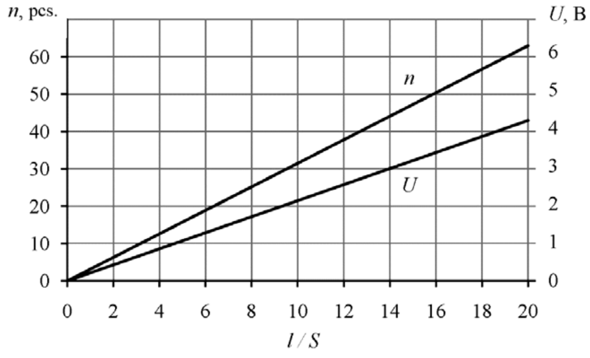

Fig. 10. Dependence of parameters n. U of the single-stage TEU on the value of relation l/s at T=300 K. ΔT=40 K and Q_0=2.0 W in the mode $Q_0/I^2)_{max}$

With the reduction of ratio l/S, operation current I increases (Fig. 16), the refrigeration coefficient does not change (E=0.38) and the number of thermoelements decreases by 2 times.

Note that for the mode $(Q_0/I^2)_{max}$ at ΔT=40 K and Q_0=2.0 W, reduction of the ratio l/S from 20 to 10 enables reduction of the failure rate λ by 50 %, and hence increase in the probability P of the failure-free operation. At the same time, the value of the operation current I increases from 1.24 to 2.48 A. and the power consumption W and refrigeration coefficient E remain constant (W=5.24 W and E=0.38) and the number of thermoelements is halved.

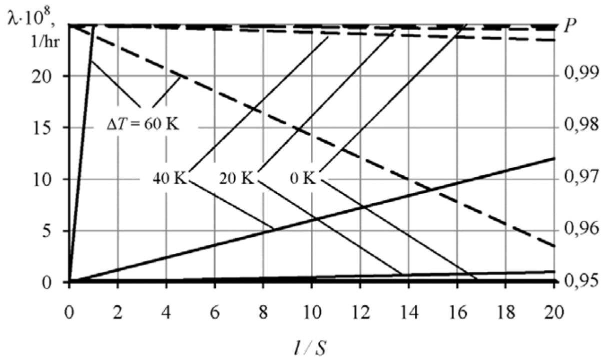

Fig. 11. Dependence of the failure rate λ (solid lines) and the probability P of failure-free operation (dotted lines) of the single-stage TEU on the value of relation l/s at T=300 K. Q_0=2.0 W and various values ΔT in the mode $(Q_0/I^2)_{max}$

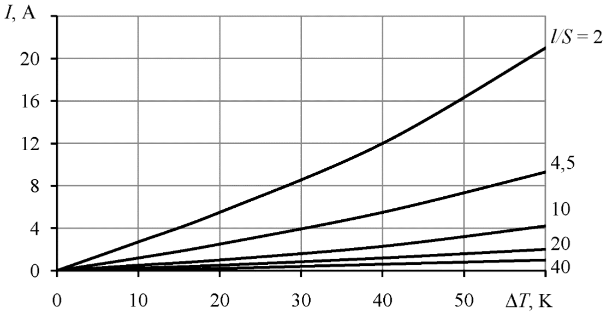

Fig. 12. Dependence of the operation current I of the single-stage TEU on the temperature variation ΔT at T=300 K, Q_0=2.0 W and various values of relation l/s in the mode $(Q_0/I^2)_{max}$

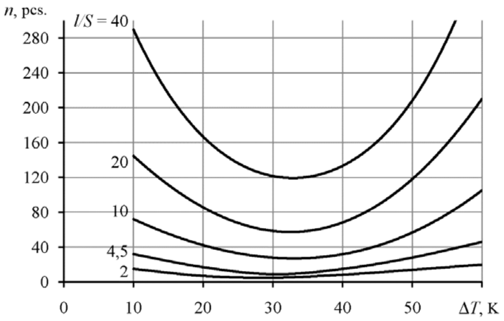

Fig. 13. Dependence of the operation current I and the number n of thermoelements of the single-stage TEU on the temperature gradient ΔT at T=300 K. Q_0=2.0 W and various values of relation l/s in the mode $(Q_0/I^2)_{max}$

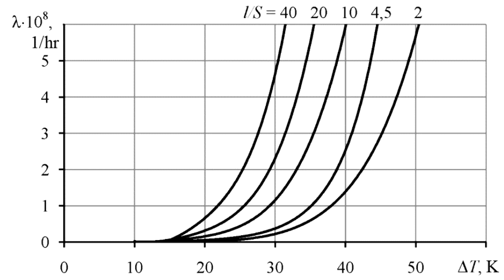

Fig. 14. Dependence of the failure rate λ of the single-stage TEU on the temperature variation ΔT at T=300 K. Q_0=2.0 W and various values of relation l/s in the mode $(Q_0/I^2)_{max}$

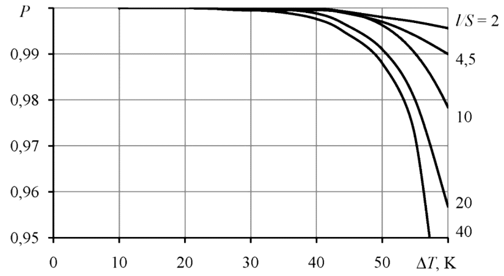

Fig. 15. Dependence of the probability P of failure-free operation of the single-stage TEU on the temperature gradient ΔT at T=300 K, Q_0=2.0 W and various values of relation l/s in the mode $(Q_0/I^2)_{max}$

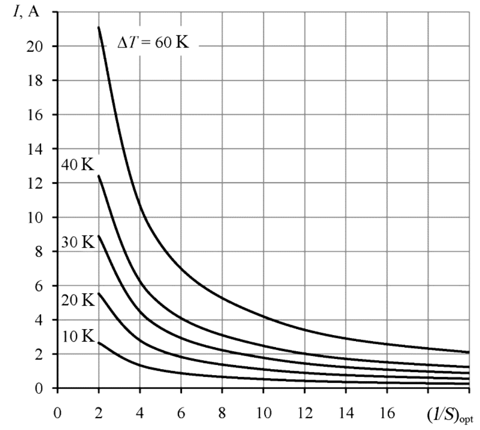

Fig. 16. Dependence of the operation current I on the optimum relation (l/s)$_{opt}$ of the single-stage TEU on the temperature gradient ΔT at T=300 K, Q_0=2.0 W and various values of ΔT in the mode $(Q_0/I^2)_{max}$

6. Discussion of the results of analysis of the influence of the branche geometry on performance of the single-stage TEU

Analysis of the calculation data for the mode $(Q_0/I)_{max}$ at ΔT=40 K and Q_0=2.0 W has shown that reduction in the thermoelement branch ratio l/S of the single-stage TEU from 20 to 10 results in the following:

– 2-fold increase in the maximum cooling power γ;

– 2.1-fold reduction in the required number n of thermoelements;

– 2-fold increase in the operating current I value;

– about a 2-fold reduction in the magnitude of the voltage U drop;

– 2-fold reduction in the failure rate λ;

– the failure-free operation probability P increases.

Besides, refrigeration coefficient E=0.34, the relative operation current B=0.71, power consumption W=5.9 W.

For the mode $(Q_0/I)_{max,}$ the following occurs at various fixed values of l/S and Q_0=2.0 W with an increase in the temperature variation ΔT from 20 to 40 K:

– 14 % lower maximum cooling power γ;

– functional dependence n=f(ΔT) has a pronounced minimum which can be explained by the maximum cooling power at an optimum ΔT;

– 47 % increase in operation current I;

– 2 times increase in the value of the voltage drop U;

– 9.4 times higher failure rate λ at l/S=20;

– reduced probability P of the failure-free operation;

– 53 % increase in the relative operation current B;

– 3 times increase in the power consumption W;

– 2.9 times reduced refrigeration coefficient E;

– 2.3 times increase in relative temperature gradient Θ.

Analysis of calculation data for the mode $(Q_0/I^2)_{max}$ at ΔT=40 K and Q_0=2.0 W has shown that with reduction from 20 to 10 in the ratio l/S of the thermoelement branch of the single-stage TEU, the following occurs:

– 2 times increase in the maximum cooling capacity γ;

– 2 times decrease in the required number n of thermoelements;

– 2 times increase in the value of the operation current I;

– 2 times reduced magnitude of voltage U drop;

– 2 times reduced failure rate λ;

– probability P of the failure-free operation increases.

Besides, refrigeration coefficient E=0.38, relative operation current B=0.5, power consumption W=5.24 W.

For the mode $(Q_0/I^2)_{max,}$ the following occurs at various fixed values of l/S and Q_0=2.0 W with an increase in the temperature gradient ΔT from 20 to 40 K:

– 14 % reduced maximum cooling power γ;

– functional relation n/f(ΔT) has a pronounced minimum which can be explained by maximum cooling power at an optimal gradient ΔT;

– 2.2 times higher operation current I;

– 1.6 times higher voltage drop U;

– 38 times higher failure rate λ;

– reduced probability P of failure-free operation;

– 2.3 times increase in the relative operation current B;

– 3.6 times increase in power consumption W;

– 3.6 times reduced refrigeration coefficient E;

– 2.3 times higher relative temperature gradient Θ.

7. Conclusions

1. We proposed the model of interconnection of the reliability indicators and the basic parameters of the single-stage TEU during variation of the thermoelement branch geometry for various temperature gradients and a fixed heat load in modes $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$. The model makes it possible to design TEU at l/S=var with consideration of restrictive requirements to size, weight, power consumption and reliability with a possibility of choice of a compromise design.

2. The possibility is defined of a significant increase in the reliability indicators of the single-stage TEU both in $(Q_0/I)_{max}$ and $(Q_0/I^2)_{max}$ modes by choosing thermoelement branch geometry with a smaller ratio l/S for the specified values of temperature gradient, heat load and power consumption.

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