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Controlling the reliability performance of a thermoelectric cooler under variable heat load

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ABSTRACT

The work is devoted to substantiation of possibility of reduction of failure rate of thermal mode support system when operating with variable load by control of reliability indicators of thermoelectric cooler. A mathematical model for evaluating the effect of variable thermal load on reliability indicators of a single-cascade thermoelectric cooler at a given temperature level of cooling, medium temperature, geometry of thermocouple branches for various current modes of operation is considered. The relationship between the cooler steady-state operation time and mass and heat capacity of the structure, relative operating current and temperature difference is presented. The results of thermal load relation with operating current, refrigerating factor, time to steady-state mode, energy input, heat dissipation capacity of the radiator, and relative failure rate are presented. Calculations have been made at a given cooling temperature level, medium temperature, temperature differential, and thermocouple branch geometry for various characteristic current operating modes. It is shown that with decreasing thermal load at a given design of thermoelectric cooler, the value of operating current decreases, thus increasing the probability of no-failure operation. The obtained relationship of thermal load with operating current and relative failure rate serves as primary information for design of thermoelectric system for providing thermal modes of thermally loaded elements with variable thermal load. Using the rate of change of temperature difference between the thermally loaded element and the cold electrode of the cooler as a control feature, it is possible to reduce the failure rate when the thermal load decreases, which contributes to increasing the average probability of no-failure operation.

Keywords: Thermal load; current mode; dynamic characteristics; reliability performance; operating current; control

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INTRODUCTION

An essential component of modern information systems are thermal management systems for electronic equipment. Functioning of electronic components is accompanied by release of thermal energy due to finite ohmic resistance of element base and transient processes. Temperature conditions of operation of electronic equipment of information systems to a large extent determine the reliability indicators, because when the temperature rises by every 10K the intensity of failures doubles. The trend towards miniaturization of the component base only exacerbates this problem. Thermal management systems are a rather complex component of information systems using cooling and heating, with the cooling of thermally stressed components being the most challenging process.

The most promising are thermoelectric ones, which differ from compression systems by small size and weight, absence of moving parts and higher reliability. Requirements for reliability of information systems are constantly increasing, and since the thermal mode system according to the reliability model is connected to the element in series, its reliability must not be lower than that of a heat-loaded element. Thermoelectric coolers (TEC) are part of the thermal management circuit of the thermally loaded element and operate under harsher temperature conditions than the rest of the control system. This leads to the fact that the achievable reliability figures for the TEC largely determine the reliability figures of the thermal management system of the heat-loaded elements. The dynamic

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characteristics of the actuator (thermoelectric cooler) are also important for the control system, as it is more inertial compared with the control components. The fundamental problem of the antagonism of system dynamics and reliability requires the search for compromise solutions, which is a relevant task for the specific application of the thermoelectric method of thermal mode assurance.

LITERATURE REVIEW

Initially, the design of thermoelectric cooling devices considered only the qualitative side of ensuring a given level of reliability [1, 2]. This approach was justified by the fact that the comparison of various designed products was based on the model and physical experiment based on the results of passing or failing accelerated tests [3, 4]. A characteristic feature of thermoelectric coolers is that they include a large number of the same thermoelements connected in series. This made it possible to apply known mathematical models to describe the life cycle indicators of products [5, 6]. The analysis of dependences of reliability indices on time for different distribution laws has shown, that for description of reliability indices of fuel and energy equipment with a probability of no-failure operation higher than 0,95 an exponential law of distribution is justified [7, 8]. In [9] it is shown, that with sufficient accuracy for practice it is possible to consider the intensity of failures of thermoelements as a constant value. Further investigations are directed to obtaining of analytical connection of reliability indexes with structural [10, 11], mechanical [12, 13], thermal [14], technological and power [15] influences. The result of research was creation of mathematical model of TEC [16], which allows quantitative description of relation between failure rate of the designed product and design and energy characteristics. However, these works did not address the dynamics and controllability of thermoelectric coolers, which are important for the functioning of control systems in which TEC is part of the feedback channel [17, 18]. In [19], studies of inertia of TEC and dependence of reliability indicators on design and power characteristics are presented, but control possibilities were not considered. In [20] the results of analysis of the possibility of control of operation modes of TEC by complex indicators, and the change in the components of the complex of basic parameters allows to focus on various features of TEC application. However, the presented research is focused on the design of coolers with constant load. However, there is a class of systems with pulsed-periodic heat load using laser emitters, intensive radiation receivers, ultrasonic emitters and power switches. A characteristic feature of such systems is that the thermal load varies over time and the system is designed for a current mode designed for the worst conditions. At the same time, load-dependent integral characteristics of thermoelectric coolers such as failure rates also change, which can potentially be used for reliability management.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this work is to reduce the failure rate of the thermal management system during variable load operation by controlling the reliability performance of the thermoelectric cooler.

In order to achieve this goal, the following tasks need to be solved:

1. To develop a model of thermoelectric cooler for operation with variable load which provides the possibility of reliability indices control.
2. To carry out analysis of relation of control action on TEC with reliability indices.

DEVELOPMENT OF A THERMOELECTRIC COOLER MODEL

At operation of TEC of various designs ($n = const, l/S = const$) at a given temperature level of cooling T_0, medium temperature T_c, operation with variable heat load Q_0 =var it is necessary to determine influence of heat load Q_0 on reliability indicators. It is necessary to select the thermal mode of operation to ensure a high average level of reliability for various operating conditions.

Let us consider the possibility of controlling the reliability indicators, namely, the relative failure rate λ/λ_0 and the probability P of no-failure operation of a single-cascade TEC under different design ($n = \text{var}$). Conditions: given cooling level T_0 =293K, temperature difference ΔT =30 K, geometry of thermocouple branches (ratio l/S =4.5) when changing thermal load from Q_0 =0.5 W to Q_0 =10 W.

To calculate the basic parameters, reliability indicators, functioning dynamics, the ratios [19].

The number of thermocouples in the TEC can be determined from the expression:

$$n = \frac{Q_0}{I_{\max}^2 R(2B - B^2 - \Theta)}. \tag{1}$$

where Q_0 is heat load, W; $I_{\max} = \frac{\bar{e}\bar{T}_0}{R}$ is maximum operating current, A; $\bar{e}$ is the average value of the thermoelectric coefficient of the thermocouple branch, V/K; T_0 is temperature of the heat absorbing junction, K; $R = \frac{l}{\bar{\sigma} S}$ is the electrical resistance of the thermocouple branch. Ohm; l and S are, respectively, the height and cross-sectional area of the thermocouple branch; $\bar{\sigma}$ is the average conductivity value of the thermocouple branch, Sm/cm; $B = I/I_{\max}$ is the relative operating current; I is the value of the operating current, A; $\Theta = \frac{T - T_0}{\Delta T_{\max}}$ is the relative temperature difference; T is the temperature of the fuel junction, K; $\Delta T_{\max} = 0{,}5\bar{z}T_0^2$ is maximum temperature difference, K; $\bar{z}$ is the average value of the thermoelectric efficiency of the thermocouple branch input materials, 1/K.

The power consumption W of the TEC can be determined from the expression [19]:

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

The voltage drop U can be written as:

$$U = 2nI_{\max}R\left(B + \frac{\Delta T_{\max}}{T_0}\Theta\right). \qquad (3)$$

The cooling factor can be determined from the expression:

$$E = \frac{Q_0}{W}. \qquad (4)$$

The relative failure rate λ/λ_0 can be calculated using the formula:

$$\frac{\lambda}{\lambda_0} = nB^2(\Theta + c)\frac{\left(B + \frac{\Delta T_{\max}}{T_0}\Theta\right)^2}{\left(1 + \frac{\Delta T_{\max}}{T_0}\Theta\right)}K_T; \qquad (5)$$

where $c = \frac{Q_0}{nI_{\max}^2 R}$ is the relative heat load; K_T is the coefficient of reduced temperatures; $\lambda_0 = 3 \cdot 10^{-8}$ is nominal failure rate, 1/hour.

The probability of no-failure operation P can be written as:

$$P = \exp(-\lambda t), \qquad (6)$$

where t is assigned resource, hours.

The time to steady-state operation τ can be determined from the expression [20]:

$$\tau = \frac{\sum_i m_i c_i + m_0 c_0}{K\left(1 + 2B\frac{\Delta T_{\max}}{T_0}\right)} \ln\frac{\gamma B_H(2 - B_H)}{2B - B^2 - \Theta}, \qquad (7)$$

where $m_0 c_0$ is the product of the mass and heat capacity of the cooling object. In our case $m_0 c_0 \to 0$ (no object); $\sum_i m_i c_i$ is the total of the products of heat capacity and mass of the structural and technological elements at the heat absorbing junction of the module for a given geometry of the thermocouple branches (ratio l/S);

$$\gamma = \frac{I_{\max H}^2 R_H}{I_{\max K}^2 R_K};$$

R_H is the electrical resistance of the thermocouple branch at the start of the cooling process, Ohm; $B_H = I/I_{\max H}$ is the relative operating current at the start of the cooling process at τ =0; $I_{\max H} = \frac{\bar{e}T}{R_H}$ is the maximum operating current at the start of the cooling process, A.

The indices *H* and *K* correspond to the start and end of the cooling process.

Provided there are equal currents at the start and end of the cooling process:

$$I = B_H I_{\max H} = B_K I_{\max K}. \qquad (8)$$

The voltage drop U on the TEC can be written in the form:

$$U = 3nI_{\max K}R_K\left(B + \frac{\Delta T_{\max}}{T_0}\Theta\right). \qquad (9)$$

The amount of energy N given can be written in the form of a ratio:

$$N = W\tau. \quad (10)$$

The required heat dissipation capacity of the radiator αF can be represented as:

$$\alpha F = \frac{Q}{T - T_c}, \quad (11)$$

$Q = Q_0 + W$ is the heat output of the TEC, W; T_c is temperature of the medium, K.

Designs of single stage TEC ($n = const$) are conditioned by using characteristic current operation modes at T_0 =293K, ΔT =30 K and geometry of thermocouple branches (ratio l/S =4.5) for maximum thermal load Q_0 =10 W.

ANALYSIS OF THE MODEL

The results of calculations of basic parameters, reliability and dynamic characteristics of single stage TEC for different typical modes of operation are shown in Table 1.

Table 1. ***Basic thermoelectric cooler parameters at***

$$T_0 = 293K, T_c = 313K, l/S = 4.5, T - T_c = 10K, \Delta T = 30K, I_{\max} = 5.42A, R \cdot 10^3 = 10.9\,Ohm, \Theta = 0.29$$

Q_0, W	B	I, A	W, W	U, V	E	τ, s	N, Ws	αF, W/K	$\frac{Q_0}{n}$	$\frac{\lambda}{\lambda_0}$	$\lambda \cdot 10^8$ 1/s	P
Mode $Q_{o\max}$ $(B=1), n=22$ pcs $(T=323K)$												
10.0	1.0	10.9	31.2	2.9	0.32	4.2	131	8.2	0.456	22.1	66.3	0.9934
7.0	0.54	5.9	9.2	1.7	0.72	6.0	59	3.3	0.32	1.7	5/0	0.99950
5.0	0.40	4.4	5.8	1.3	0.87	8.0	46	2.1	0.23	0.58	1.7	0.99983
3.0	0.30	3.2	3.3	1.0	0.91	11.4	38	1.3	0.14	0.13	0.38	0.999962
1.0	0.20	2.2	1.7	0.78	0.59	21.8	37	0.54	0.046	0.024	0.072	0.999993
0.5	0.18	2.0	1.4	0.73	0.35	29.4	42	0.40	0.023	0.015	0.045	0.999995
										245.49	73.65	0.99266
Mode $(nI)_{\min}$ $(B=1), n=31..3$ pcs $(T=323K)$												
10.0	0.54	5.9	13.9	2.4	0.72	6.1	85	4.8	0.32	2.45	7.4	0.99926
7.0	0.40	4.3	8.1	1.9	0.86	8.1	65	3.0	0.22	0.67	2.0	0.99980
5.0	0.32	3.5	5.5	1.6	0.91	10.3	57	2.1	0.16	0.26	0.77	0.99992
3.0	0.25	2.7	3.6	1.3	0.84	14.4	52	1.3	0.096	0.091	0.27	0.999973
1.0	0.19	2.0	2.2	1.1	0.45	25.5	56	0.64	0.032	0.026	0.079	0.999992
0.5	0.17	1.9	1.9	1.0	0.26	33.7	65	0.48	0.016	0.019	0.056	0.999994
										2.516	10.55	0.99885
Mode $(nI\tau\,\lambda/\lambda_0)_{\min}$ $(B=1), n=63$ pcs $(T=323K)$												
10.0	0.32	3.5	11.0	3.1	0.91	10.3	114	4.2	0.16	0.52	1.6	0.99984
7.0	0.27	2.9	8.0	2.8	0.87	13.2	106	3.0	0.11	0.24	0.72	0.999930
5.0	0.24	2.6	6.4	2.5	0.78	16.1	103	2.3	0.080	0.14	0.41	0.999959
3.0	0.20	2.2	5.0	2.3	0.60	21.2	106	1.6	0.048	0.073	0.22	0.999978
1.0	0.17	1.9	3.9	2.0	0.26	33.7	130	0.97	0.016	0.037	0.11	0.999989
0.5	0.165	1.8	3.6	2.0	0.14	42.0	150	0.80	0.008	0.03	0.092	0.999991
										1.04	3.12	0.99969
Mode $\lambda_{\min}$ $(B=1), n=159$ pcs $(T=323K)$												
10.0	0.22	2.4	14.3	6.0	0.70	18.4	263	4.9	0.063	0.25	0.75	0.999925
7.0	0.20	2.2	12.4	5.7	0.57	22.1	273	3.9	0.044	0.17	0.52	0.999948
5.0	0.19	2.0	11.1	5.4	0.45	25.7	285	3.2	0.0314	0.13	0.40	0.999960
3.0	0.18	1.9	10.0	5.2	0.30	31.6	316	2.6	0.019	0.10	0.30	0.999970
1.0	0.164	1.8	8.9	5.0	0.11	45.3	404	2.0	0.0063	0.075	0.23	0.999977
0.5	0.160	1.75	8.7	4.9	0.00	54.0	467	1.8	0.0031	0.070	0.21	0.999979
										0.80	2.4	0.99976

Source: **compiled by the authors**

As the thermal load decreases Q_0 from Q_0 =10 W to Q_0 =0.5 W for a given temperature level of cooling T_0 =293 K, temperature differential ΔT =30 K and branch geometry of thermocouples (ratio l/S =4.5) for single stage TECs of different designs:

– the relative operating current (Fig. 1) for different characteristic current operating modes decreases. The relative operating current B decreases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed thermal load Q_0. The minimum value of the relative operating current $B_{\min}$ is ensured in mode $\lambda_{\min}$;

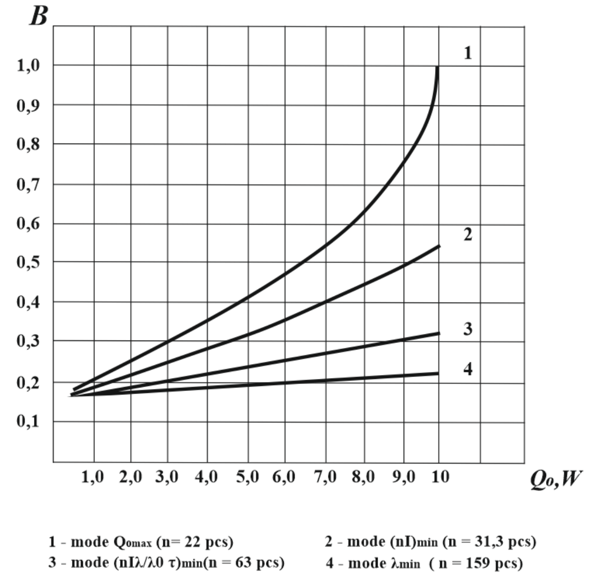

Fig. 1. **Dependence of relative operating current B of a single stage TEC on heat load Q_0 for different characteristic current modes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

***Source:* compiled by the authors**

– the operating current I decreases (Fig. 2) for the various characteristic current operating modes. The operating current I decreases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ with a fixed thermal load Q_0. The minimum operating current $I_{\min}$ is ensured at $\lambda_{\min}$;

– the functional dependence of the coefficient $E = f(Q_0)$ on the value of thermal load Q_0 has a maximum for various characteristic current modes of operation (Fig. 3). So for initial current mode $Q_{0\max}$: $E_{\max}$ =0.91 at Q_0 =3.0 W, which corresponds to B_{opt} =0.30 at Θ =0.29, i.e. a mode close to $(nI\tau\,\lambda/\lambda_0)_{\min}$. For current mode $(nI)_{\min}$: $E_{\max}$ =0.91 at Q_0 =5.0 W, which corresponds to a mode B_{opt} =0.32 at Θ =0.29, close to the mode $(nI\tau\,\lambda/\lambda_0)_{\min}$;

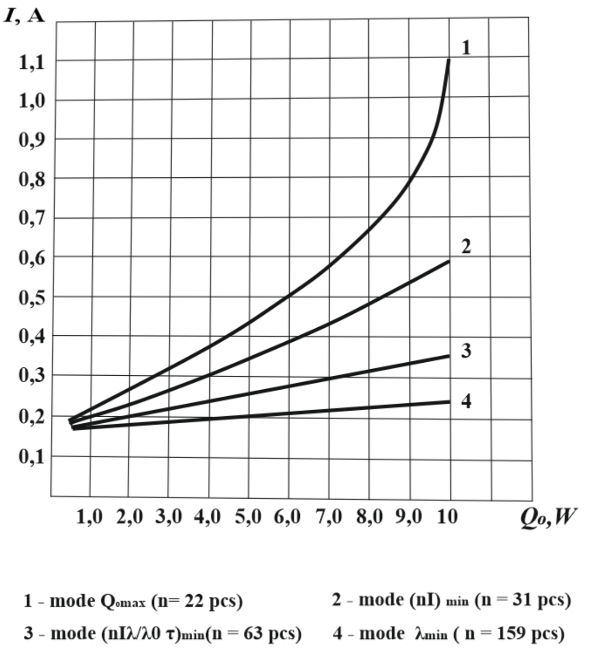

Fig. 2. **Dependence of operating current I magnitude of single stage TEC on heat load Q_0 magnitude for different characteristic current modes at T_0 =293K; T_c =313K; ΔT =30K; l/S =4.5**

***Source:* compiled by the authors**

– the voltage drop U is reduced (Fig. 4) for the various characteristic current operating modes. The voltage drops U increases in pre-mode $Q_{0\max}$ at a fixed thermal load $\lambda_{\min}$. The maximum voltage drop $U_{\max}$ is ensured in mode $\lambda_{\min}$;

– the cooling capacity per thermocouple $\frac{Q_0}{n}$ is reduced (Fig. 5) for the various characteristic current operating modes. The cooling capacity per thermocouple $\frac{Q_0}{n}$ increases from mode to mode $\lambda_{\min}$ at $Q_{0\max}$ a fixed heat load Q_0. The maximum cooling capacity per thermocouple $(\frac{Q_0}{n})_{\max}$ is achieved in mode $Q_{0\max}$;

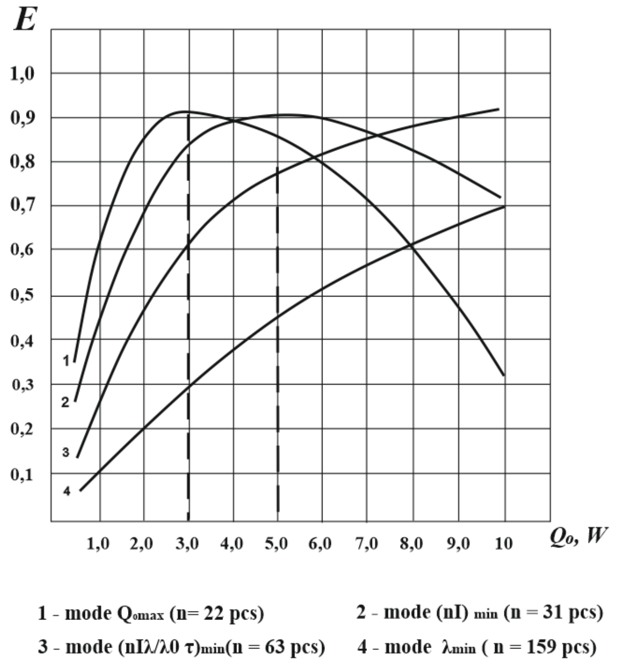

Fig. 3. **Dependence of the cooling factor E of a single stage TEC on the heat load E for different characteristic current regimes at T_0 =293K; T_c =313K; ΔT =30K; l/S =4.5**

***Source:* compiled by the authors**

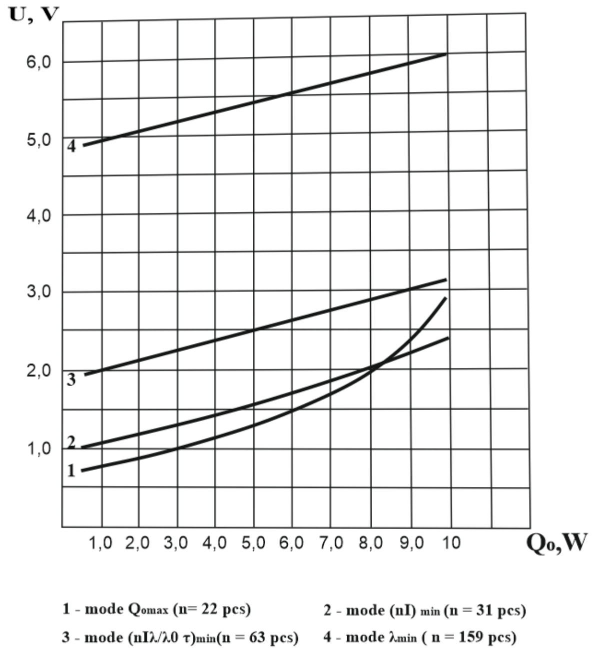

Fig. 4. **Dependence of voltage drop U of single stage TEC on heat load value Q_0 for different characteristic current modes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

***Source:* compiled by the authors**

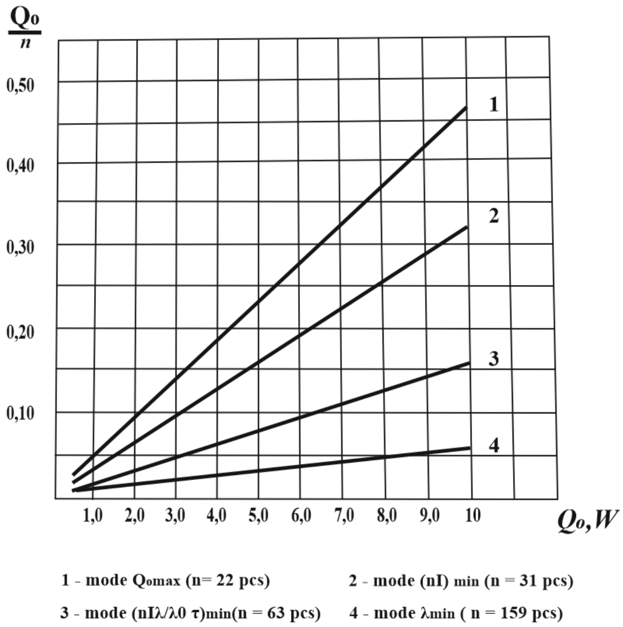

Fig. 5. **Dependence of cooling capacity per element $\frac{Q_0}{n}$ of a single stage TEC on the heat load Q_0 for different characteristic current regimes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

***Source:* compiled by the authors**

– the ramp-up time τ increases (Fig. 6) for the various characteristic current operating modes, because the relative operating current B, and consequently the operating current value I, decreases. The ramp-up time τ decreases from mode $\lambda_{\min}$ to mode $Q_{0\max}$ with a fixed thermal load Q_0. The shortest ramp-up time $\tau_{\min}$ is ensured in $Q_{0\max}$;

– the functional dependence of the amount of energy expended $N = f(Q_0)$ on the value of the thermal load Q_0 has a minimum for the various characteristic current operating modes (Fig. 7). Thus, for mode $Q_{0\max}$: $N_{\min}$ =37 W sec at Q_0 =3.0 W, for mode $(nI\tau\,\lambda/\lambda_0)_{\min}$: $N_{\min}$ =103 W sec at Q_0 =5.0 W. The amount of energy expended decreases from mode $\lambda_{\min}$ to mode $Q_{0\max}$ at a fixed thermal load Q_0. The minimum amount of energy N consumed is ensured in mode $Q_{0\max}$;

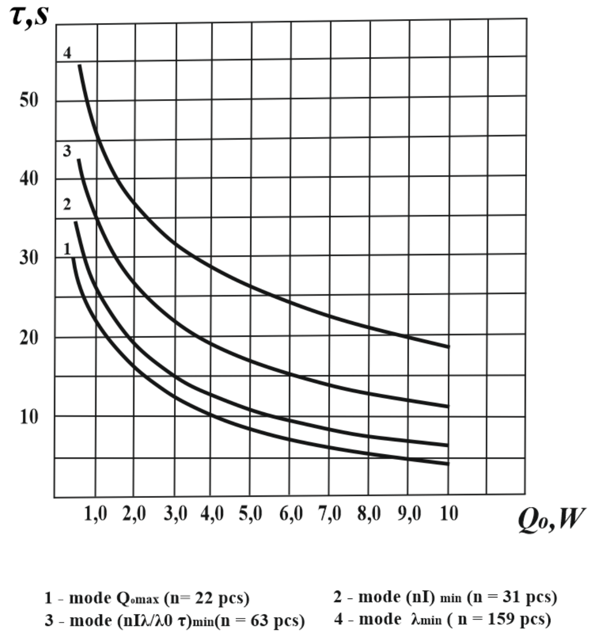

Fig. 6. **Dependence of time to steady-state operation τ of single stage TEC on the value of thermal load Q_0 for different characteristic current modes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

Source: **compiled by the authors**

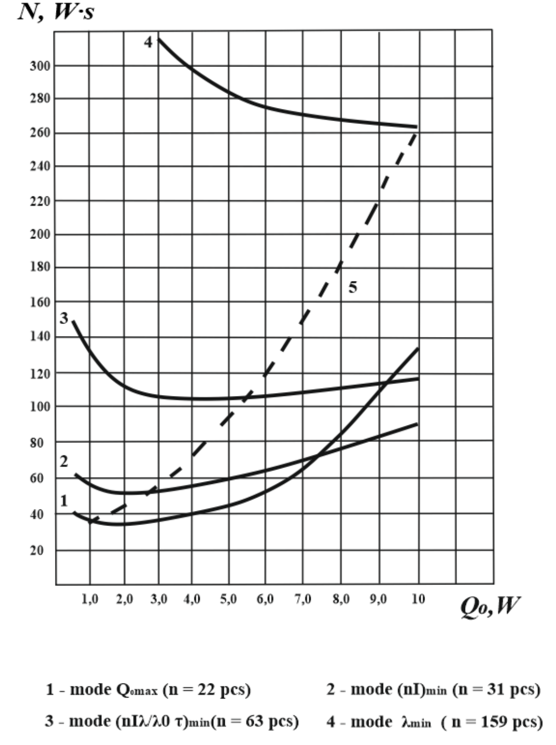

Fig. 7. **Dependence of the amount of energy N expended by a single-stage TEC on the heat load Q_0 for different characteristic current regimes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

Source: **compiled by the authors**

– the relative failure rate λ/λ_0 decreases (Fig. 8) for the various characteristic current operating modes. The relative failure rate λ/λ_0 decreases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed thermal load Q_0. The minimum relative failure rate $(\lambda/\lambda_0)_{\min}$ is ensured in $\lambda_{\min}$;

– the probability of failure-free operation P increases (Fig. 9) for the various characteristic current operating modes. The fault probability P increases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed thermal load Q_0. The maximum probability of no-failure operation $P_{\max}$ is ensured in the $\lambda_{\min}$;

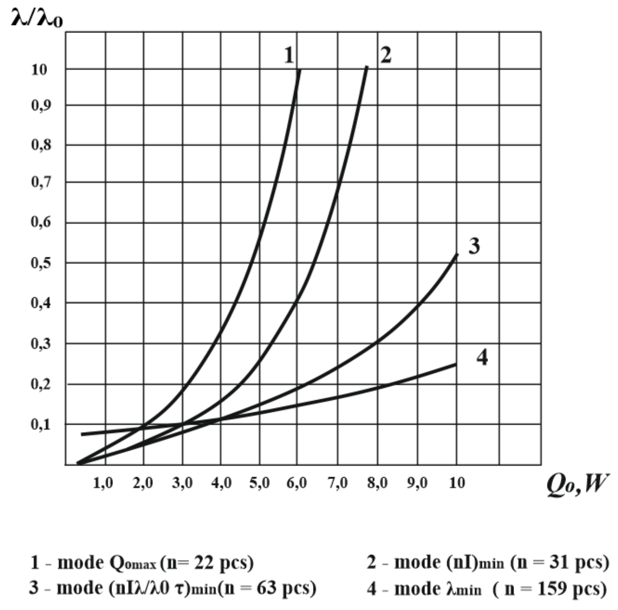

Fig. 8. **Dependence of the relative failure rate λ/λ_0 of a single stage TEC on the thermal load Q_0 for different characteristic current regimes at T_0 =293K, T_c =313K, ΔT =30K, ΔT =4.5**

Source: **compiled by the authors**

– the required heat dissipation surface of the heat sink αF is reduced (Fig. 10) for the various characteristic current operating modes. The maximum required heat dissipation capacity of the heatsink αF can be achieved in $(nI\tau\,\lambda/\lambda_0)_{\min}$.

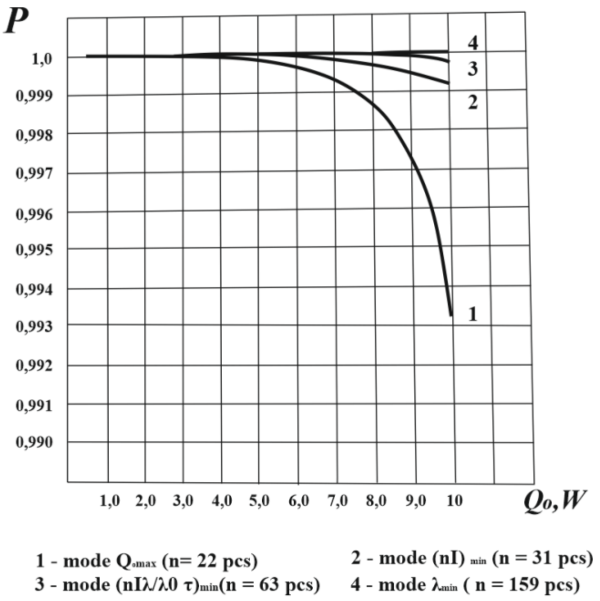

Fig. 9. **Relation of single stage TEC failure probability P to thermal load Q_0 for different characteristic current modes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

Source: **compiled by the authors**

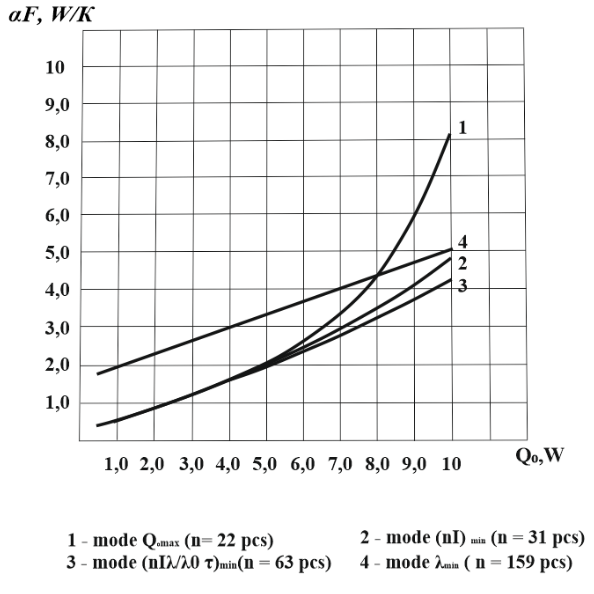

Fig. 10. **Dependence of heat dissipation capacity αF of single stage TEC on heat load value Q_0 for different characteristic current modes at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

Source: **compiled by the authors**

DISCUSSION OF ANALYSIS RESULTS

Analysis of the results showed that with reduction of heat load Q_0 from Q_0 =10 W to Q_0 =0.5 W for a given temperature level of cooling Q_0 =293 K, temperature differential ΔT =30 K and geometry of thermocouple branches (ratio l/S =4.5):

for the initial mode $Q_{0\max}$ (n=22 pieces):

– the relative operating current B by 46 %, the operating current I by 46%, the voltage drop U by 41 %, the energy N input by 55%, the required heat dissipation capacity of the heat sink αF by 60 %, the cooling capacity per thermocouple $\frac{Q_0}{n}$ by 30 % and the relative failure rate λ/λ_0 by 13 times;

– increases: refrigerating factor E by 2.25 times, probability of no-failure operation from P =0.9934 to P =0.99950, time to steady-state operation τ by 30%;

for the initial characteristic current mode $(nI)_{\min}$ (n =31 pcs.):

– the relative operating current B by 26%, the operating current I by 27 %, the voltage drop U by 21 %, the energy input N by 23 %, the required heat dissipation capacity of the heat sink αF by 38 %, the cooling capacity per thermocouple $\frac{Q_0}{n}$ by 31% and the relative failure rate λ/λ_0 by a factor of 3.7;

– increases: cooling factor E by 19%, ramp-up time τ by 33 %, no-failure probability from P =0.99926 to P =0.99980;

for the initial characteristic current mode $(nI\tau\,\lambda/\lambda_0)_{\min}$:

– the relative operating current B by 16%, operating current I by 17 %, voltage drop U by 9.7 %, energy consumption N by 7 %, heat dissipation capacity required αF by 29 %, cooling capacity per thermocouple $\frac{Q_0}{n}$ by 31 %, relative failure rate λ/λ_0 by 2.2 times, cooling factor E by 4.4 %;

– increases: steady-state operating time τ by 28%, no-failure probability P from P =0.99984 to P =0.999930;

for the initial characteristic current mode $\lambda_{\min}$:

– decreases: operating current B by 9 %, operating current I by 8.3 %, voltage drop U by 5 %, cooling factor E by 18.6 %, necessary heat dissipation capacity per heatsink αF by 20 %, cooling capacity per thermocouple $\frac{Q_0}{n}$ by 30 %, relative failure rate λ/λ_0 by 32 %;

– increases: ramp-up time τ by 20 %, energy input N by 3.8%, no-failure probability P from P =0.999925 to P =0.999948.

Fig. 11 shows the dependence of the operating current I and the relative failure rate λ/λ_0 on the thermal load Q_0 for the mode $(nI\tau\,\lambda/\lambda_0)_{\min}$ (n =63 pcs.) at $T_0 = 293K, T_c = 313K, l/S = 4.5, \Delta T = 30K$.

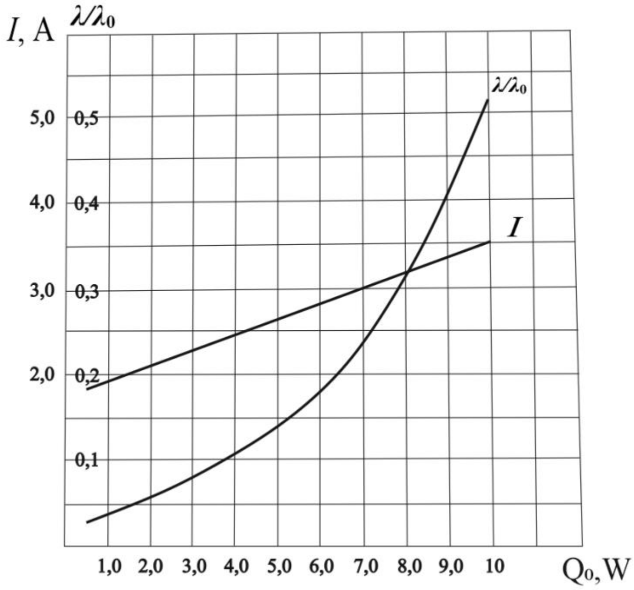

Fig. 11. **Dependence of operating current magnitude I, relative failure rate λ/λ_0 of single stage TEC on heat load magnitude Q_0 in mode $(nI\tau\,\lambda/\lambda_0)_{\min}$ at T_0 =293K, T_c =313K, ΔT =30K, l/S =4.5**

Source: **compiled by the authors**

As the thermal load Q_0 decreases, the operating current I and the relative failure rate λ/λ_0 decreases. Thus, for example, with decreasing thermal load Q_0 value from Q_0 =10W to Q_0 =7.0W, i.e. by 30 %, the operating current value I decreases from I =3.5A to $= I$ 2.9A, i.e. by 17 %, and the relative failure rate λ/λ_0 decreases from λ/λ_0 =0.52 to λ/λ_0 =0.24, i.e. by a factor of 2.2.

The data obtained is sufficient to construct a thermoelectric system for thermal management of thermally loaded electronic elements under variable thermal load. The primary information can be the temperature difference between the thermally loaded element, its nominal temperature and its rate of change. Realization of the system is possible on the principles of fuzzy logic, as the terms to use the basic current modes from $\lambda_{\min}$ to $Q_{0\max}$. It is obvious; that at low rates of temperature difference change it is possible to manage the reliability indicators of the system, shifting the characteristic towards low failure rates, thus reducing the average failure rate of the system.

CONCLUSIONS

1. A model of interrelation of main parameters, reliability indicators and dynamic characteristics of a single stage TEC with variable thermal load at a given temperature level of cooling T_0, medium temperature T_c, geometry of thermocouple branches for various current modes of operation has been developed.

2. The analysis of research results showed the possibility of controlling the reliability indicators of a single-stage TEC of a given design by taking into account the change in the value of thermal load. With reduction of thermal load at the given design of single stage TEC decreases the value of operating current, which allows reducing the relative intensity of failures.

3. The practical result of the study is the substantiation of the possibility of increasing the probability of failure-free operation of tracking systems when receiving intensive pulsed laser radiation, emitting sounding information systems with critical limitations on mass-size, energy, reliability and dynamic characteristics.

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Управління показниками надійності термоелектричних охолоджувачів при змінному тепловому навантаженні

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АНОТАЦІЯ

Роботу присвячено обґрунтуванню можливості зниження інтенсивності відмов системи забезпечення теплових режимів під час роботи зі змінним навантаженням шляхом керування показниками надійності термоелектричного охолоджувача. Розглянуто математичну модель оцінки впливу змінного теплового навантаження на показники надійності однокаскадного термоелектричного охолоджувального пристрою за заданого температурного рівня охолодження, температури середовища, геометрії гілок термоелементів для різних струмових режимів роботи. Наведено зв'язок часу виходу охолоджувача на стаціонарний режим із масою і теплоємністю конструкції, відносним робочим струмом, перепадом температур. Наведено результати зв'язку теплового навантаження з робочим струмом, холодильним коефіцієнтом, часом виходу на стаціонарний режим, енергією, що витрачається, тепловідвідної здатністю радіатора, відносною інтенсивністю відмов. Розрахунки проведено за заданого температурного рівня охолодження, температури середовища, перепаду температур, геометрії гілок термоелементів для різних характерних струмових режимів роботи. Показано, що зі зменшенням теплового навантаження за заданої конструкції термоелектричного охолоджувача, зменшується величина робочого струму, що дає змогу збільшити ймовірність безвідмовної роботи. Отриманий зв'язок теплового навантаження з робочим струмом і відносною інтенсивністю відмов слугує первинною інформацією для проектування термоелектричної системи забезпечення теплових режимів тепло навантажених елементів зі змінним тепловим навантаженням.

Використовуючи швидкість зміни перепаду температур між тепло навантаженим елементом і холодним електродом охолоджувача як ознаку керування, можна знизити інтенсивність відмов при зменшенні теплового навантаження, що сприяє підвищенню середньої ймовірності безвідмовної роботи.

Ключові слова: теплове навантаження, струмовий режим, динамічні характеристики, показники надійності, робочий струм, керування.

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