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Reliability control of a thermoelectric cooler with changes in ambient temperature

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ABSTRACT

The paper presents the development of method of thermoelectric system reliability indexes control for providing thermal modes of radio electronic equipment, based on thermoelectric coolers medium temperature variation. A mathematical model for investigating influence of the environment temperature variation on the reliability performance of a single-cascade thermoelectric cooler at a given temperature level of cooling, thermal load, geometry of thermoelement branches for different characteristic current operating modes is considered. The results of calculations of the basic parameters, reliability indices, dynamic characteristics and the analysis of dependences are given for revealing the peculiarities of control processes. It is shown that decreasing the medium temperature at a given chiller design decreases the operating current, increases the cold-productivity, and decreases the time of reaching a steady-state operating mode for various characteristic current operating modes. The time to steady-state operation decreases from the minimum failure rate to the maximum cooling capacity at a fixed medium temperature. The minimum steady-state operation time is ensured in maximum cooling capacity mode. Reduction of such significant for control indices as the amount of consumed energy for different characteristic current operation modes, required heat dissipation capacity of the radiator, time of reaching the steady-state mode is noted. Analysis of research results has shown that it is possible to control indicators of reliability of a single-stage cooler of a given design by changing the medium temperature by changing the value of operating current. A change in the medium temperature of the thermoelectric cooler due to an external supporting device makes it possible to vary the reliability indices and to find a compromise between the reliability, dynamics and cooling capacity of the thermal mode support system.

Keywords: Thermoelectric cooler; thermal mode; medium temperature; dynamic characteristics; reliability index control

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INTRODUCTION

The three-component structure of the thermal management model includes heat extraction, transfer and dissipation to the environment. The thermoelectric method of thermal management has significant advantages over the compression method in terms of reliability, dynamic performance, ease of control, small size and weight. However, thermoelectric coolers have a lower cooling capacity, which limits the scope of application to local heat-loaded objects. The combined use of thermoelectric and other types of coolers has the potential to provide new system possibilities. The most critical part of the thermal management system is the thermoelectric cooler; as it is in direct contact provision system is under more preferential with the heat-sensitive component. The rest of the temperature conditions, so the focus of research on improving reliability and dynamics is mainly on thermoelectric coolers. The considered design and energy methods of improving reliability and dynamics of thermoelectric coolers contribute to solving problems of controllability of thermal mode support systems. However, these methods do not allow managing reliability indicators operatively. They refer to the design of thermoelectric devices and are designed for fixed modes, which is important for critical operating conditions. The task of management of reliability indicators of the system of ensuring thermal modes of electronic equipment in real time processes remains actual.

LITERATURE REVIEW

Qualitative approach of reliability indicators representation [1, 2] is based on binary description of non-repairable products according to the principle of serviceability, typical representative of which are thermoelectric coolers. Accelerated tests are typical for such representation in the analysis of experimental studies [3, 4]. Serial connection of thermoelements and failure of any of them leads to the cooler inoperability. This makes it possible to apply well-developed mathematical models to describe the life cycle indicators of the products [5, 6]. When the probability of failure-free operation is above 0.95 for thermoelectric coolers, it is correct to apply an exponential law of distribution, which promotes the use of analytical models [7, 8]. A considerable number of series-connected thermoelements in the cooler allowed considering the failure rate as a constant value with sufficient accuracy [9]. This provided obtaining of analytical connection of reliability indexes with structural [10, 11], mechanical [12, 13], thermal [14], technological and power [15] indexes. The result of this research was development of mathematical model of thermoelectric cooler [16], which quantitatively connects failure rate with design and energy indices. However, these developments were limited to static models and did not take into account dynamics issues relevant for thermal management systems [17, 18]. In [19] the results of studies of inertia of a solid-state cooler and connection of reliability indicators with design and energy performance are given. However, control issues related to the use of thermoelectric coolers in the feedback circuit have not been discussed. The issues of thermoelectric cooler operation mode control by complex indicators are considered in [20]. Variation of the complex parameters is focused on different features of cooler application, taking into account the mass-size characteristics, power consumption, and time to reach the steady-state mode. At the same time, there is a class of tasks that needs the management of reliability indicators to increase the lifetime of the system. Considerable time of functioning of such systems is in a stand-by mode of tracking, for which current modes with low intensity of failures can be used, and only for a short time they function in a critical operating mode. Obviously, the resulting uptime of the system can be increased by controlling the failure rate.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of the work is to determine the possibility of operational management of reliability indicators of thermoelectric cooler of the system to provide thermal modes of electronic equipment.

To achieve this goal, it is necessary to solve the following tasks:

1. To develop a reliability-oriented mathematical model of thermoelectric cooler, linking design, energy, dynamic and reliability characteristics.
2. To analyses the developed model to identify significant links of control action with reliability performance.

DEVELOPMENT OF A THERMOELECTRIC COOLER MODEL

When constructing single stage thermoelectric coolers (TEC) with a given temperature level T_0 of cooling and a constant heat load Q_0 operating at varying media temperatures T_c, it is necessary to determine the influence of the media temperature T_c on the reliability performance.

For this purpose, we first determine the number n of thermocouples for characteristic current modes of operation at the maximum medium temperature $T_{c\max}$. Then, at a given number n of thermocouples for different characteristic current modes of operation, determine the basic parameters, reliability indicators and dynamic characteristics of a single-stage thermoelectric cooler when the medium temperature T_c varies in the range $T_{c\min}$ from to $T_{c\max}$.

Let's consider a possibility of management of reliability indexes, namely, relative failure rate λ/λ_0 and probability of non-failure operation P of single-cascade thermoelectric cooler of different designs ($n=Var$, l/S =4.5) at changing of environment temperature T_c from T_c =333K (+60ºC) to T_c =293K (+20ºC) for given cooling level T_0 =293K, thermal load Q_0 =5.0 W and temperature of heat-generating junctions $T=T_c+5K$ and using branch geometry (ratio l/S).

The results of calculations of the main parameters, reliability and dynamic characteristics of single stage TECs of different designs are shown in Table 1.

The main significant parameters were calculated for the initial characteristic current operation modes at T_c =333K: $Q_{o\max}\,(B=1),(n=14)$; 2) $(nI)_{\min},(n=17)$; 3) $(nI\,{}^{\lambda}\!/\!{}_{\lambda_0}\,\tau)_{\min},(n=27)$;; 4) $\lambda_{\min},(n=61)$, followed by a change of medium temperature to T_c =293 K.

Table 1. **The results of the basic parameter calculations at**
$T_0 = 293K, \quad T - T_c = 5K, \quad l/S = 4.5, \quad Q_0 = 5.0W$

T_c, K	B	$R \cdot 10^3$ Ω	$I_{\max}$, A	I, A	W, W	U, V	E	Θ	τ, s	N, Ws	$\frac{Q_0}{n}$	αF, W/K	λ / λ_0	$\lambda \cdot 10^8$, $1/h$	P
Mode $Q_{o\max}$ $(B=1)$, $n=14$, $T=333K$															
333	1.0	5.5	10.8	10.8	20.8	1.9	0.24	0.44	5.9	124	0.36	5.2	14.1	42.3	0.9958
323	0.67	5.4	11.0	7.4	9.6	1.3	0.52	0.34	5.7	55	0.36	2.9	7.9	8.6	0.99914
313	053	5.2	11.3	6.0	6.1	1.0	0.82	0.24	4.6	28	0.36	2.2	1.0	3.0	0.99970
303	0.43	5.1	11.5	4.9	3.9	0.80	1.3	0.15	2.9	11	0.36	1.8	0.37	1.1	0.99989
293	0.36	5.0	11.54	4.1	2.5	0.60	2.0	0.05	1.1	2.7	0.36	1.5	0.14	0.42	0.999958
Mode $(nI)_{\min}$, $n=17$, $T=333K$															
333	0.66	5.5	10.8	7.2	12.1	1.7	0.41	0.44	7.7	93	0.29	3.4	3.4	10.3	0.99898
327	0.53	5.4	11.0	5.9	7.9	1.3	0.64	0.34	7.0	53	0.29	2.6	1.3	4.0	0.99960
313	0.43	5.2	11.3	4.8	5.1	1.0	0.98	0.24	5.7	29	0.29	2.0	0.48	1.45	0.99986
303	0.35	5.1	11.5	4.0	3.2	0.80	1.6	0.15	3.8	12	0.29	1.6	0.17	0.51	0.999948
293	0.28	5.0	11.54	3.2	1.9	0.60	2.6	0.05	1.4	2.7	0.29	1.4	0.06	0.18	0.999983
Mode $(nI \lambda / \lambda_0 \, \tau)_{\min}$, $n=27$, $T=333K$															
333	0.48	5.5	10.8	5.1	10.4	2.0	0.48	0.44	11.0	115	0.18	3.1	1.3	4.0	0.99960
327	0.39	5.4	11.0	4.3	6.9	1.6	0.73	0.34	9/8	68	0.18	2.4	0.53	1.6	0.99984
313	0.31	5.2	11.3	3.5	4.3	1.3	1.15	0.24	8.2	35	0.18	1.9	0.17	0.52	0.999948
303	0.24	5.1	11.5	2.7	2.5	0.92	2.0	0.15	5.5	14	0.18	1.5	0.05	0.15	0.999985
293	0.20	5.0	11.54	2.1	1.6	0.75	3.2	0.05	2.1	3.3	0.18	1.3	0.016	0.05	0.9999951
Mode $\lambda_{\min}$, $n=61$, $T=333K$															
333	0.34	5.5	10.8	3.7	13.3	3.6	0.38	0.44	18.1	241	0.083	3.7	0.75	2.3	0.99977
327	0.27	5.4	11.0	3.0	8.2	2.8	0.61	0.34	17.1	141	0.083	2.6	0.25	0.75	0.999925
313	0.20	5.2	11.3	2.3	4.8	2.1	1.0	0.24	14.5	69	0.083	2.0	0.07	0.20	0.999980
303	0.15	5.1	11.5	1.7	2.3	1.4	2.2	0.15	10.4	24	0.083	1.5	0.012	0.036	0.9999964
293	0.09	5.0	11.54	1.0	0.80	0.80	6.3	0.05	4.6	3.6	0.083	1.2	0.001	0.003	0.9999997

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

To calculate the main parameters, reliability indicators, the dynamics of operation of the TEC complex, we use the following designations [16]:

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

where Q_0 is heat load, W; $I_{\max} = \frac{e\bar{T}_0}{R}$ 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:

$$W_K = 2nI_{\max K}^2 R_K B_K (B_K + \frac{\Delta T_{\max}}{T} \Theta). \qquad (2)$$

The voltage drop U can be written as:

$$U_K = \frac{W_K}{I}. \qquad (3)$$

The cooling factor can be determined from the expression:

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

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

$$\lambda / \lambda_0 = nB_K^2 (\Theta + C) \frac{(B_K + \frac{\Delta T_{\max}}{T_0}\Theta)^2}{(1 + \frac{\Delta T_{\max}}{T_0}\Theta)^2} K_T, \quad (5)$$

where $C = \frac{Q_0}{nI_{\max K}^2 R_K}$ 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:

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

where t is assigned resource, hours.

The time to steady-state operation τ can be determined from the expression [16]:

$$\tau = \frac{m_0 C_0 + n \sum_i m_i C_i}{nK \left(1 + 2B_K \frac{\Delta T_{\max}}{T_0}\right)} \ln \frac{\gamma B_H (2 - B_H)}{2B_K - B_K^2 - \Theta}, \quad (7)$$

where $\gamma = \frac{I_{\max H}^2 R_H}{I_{\max K}^2 R_K}$, $m_0 C_0$ 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); 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.

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

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

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

$$U = 2nI_{\max K} R_K (B + \frac{\Delta T_{\max}}{T_0}\Theta). \quad (9)$$

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:

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

where α is the heat transfer coefficient, F is the surface area of the radiator, $Q = Q_0 + W$ is the heat output of the TEC, W; T_c is temperature of the medium, K.

ANALYSIS OF THE MODEL

With the reduction of the medium temperature T_c from T_c =333K to T_c =293K for a given temperature level of cooling T_0 =293K, heat load Q_0 =0.5W, branch geometry of thermocouples (ratio l/S =4.5) for single stage TECs of different designs:

– the relative operating current B (Fig.1) decreases for various initial characteristic current operating modes. The relative operating current B decreases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed medium temperature T_c. The minimum relative operating current $B_{\min}$ is ensured in $\lambda_{\min}$;

– the operating current I (Fig. 2) decreases for various initial characteristic current operating modes. The operating current I decreases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed medium temperature T_c.

The minimum operating current $I_{\min}$ is ensured in $\lambda_{\min}$;

– the cooling factor E increases (Fig.3) for the various initial characteristic current operating modes. The maximum cooling factor $E_{\max}$ is ensured in $(nI\,{}^{\lambda}\!/_{\lambda_0}\,\tau)_{\min}$;

– the voltage drop U is reduced (Fig. 4) for the different initial characteristic current modes of operation. The maximum voltage drop $U_{\max}$ is ensured in $\lambda_{\min}$;

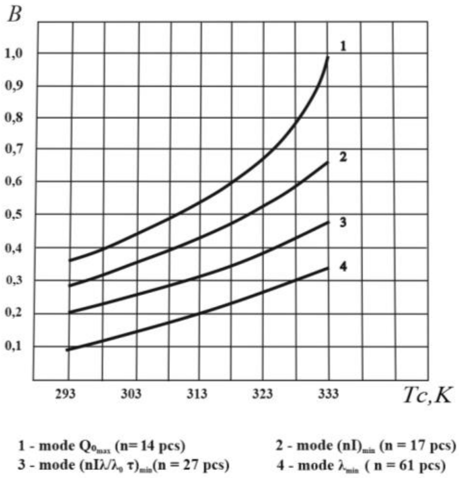

Fig. 1. **Relative operating current B vs medium temperature T_c for various initial characteristic current operating conditions at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W**

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

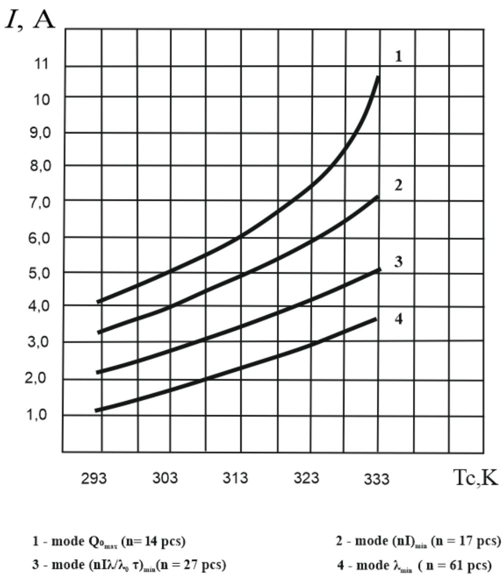

Fig. 2. **Dependence of operating current I magnitude on medium temperature T_c for different initial characteristic current operation modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W**

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

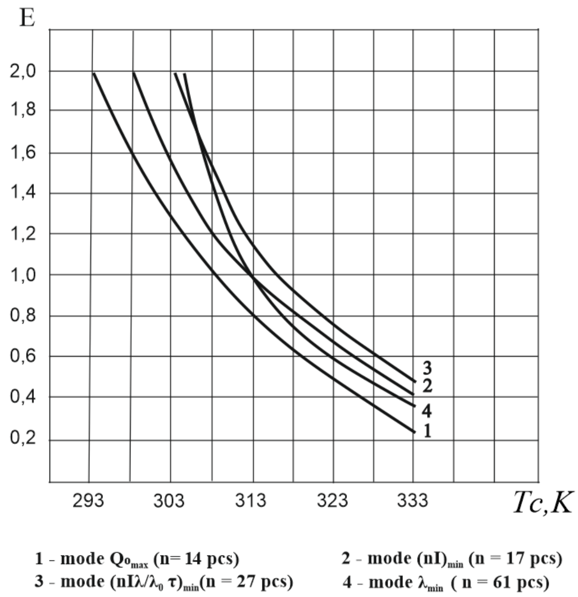

Fig. 3. **Dependence of refrigerating factor E on medium temperature T_c for different initial characteristic current operating conditions at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W**

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

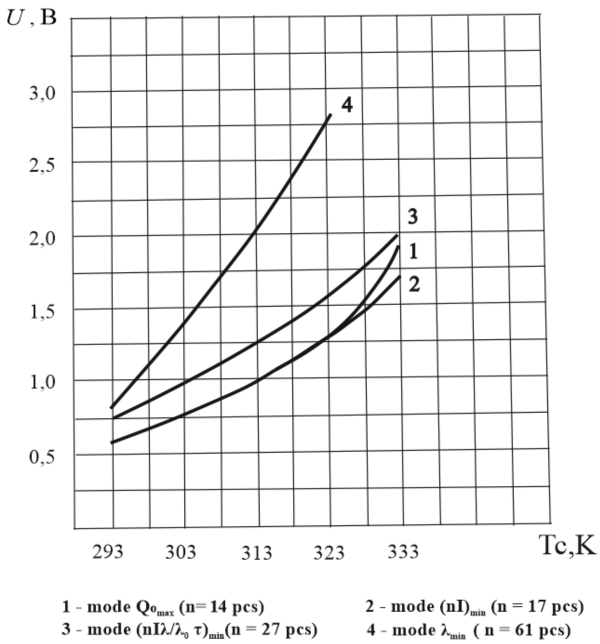

Fig. 4. **Dependence of voltage drop U on medium temperature T_c for different initial characteristic current operating modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 0.5W**

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

– the relative temperature difference Θ (Fig. 5) decreases for the different initial characteristic

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current operating modes. The cooling capacity per thermocouple Q_0/n remains constant for the different initial characteristic current operating modes. The maximum cooling capacity per thermocouple $(Q_0/n)_{\max}$ is achieved in $Q_{0\max}$;

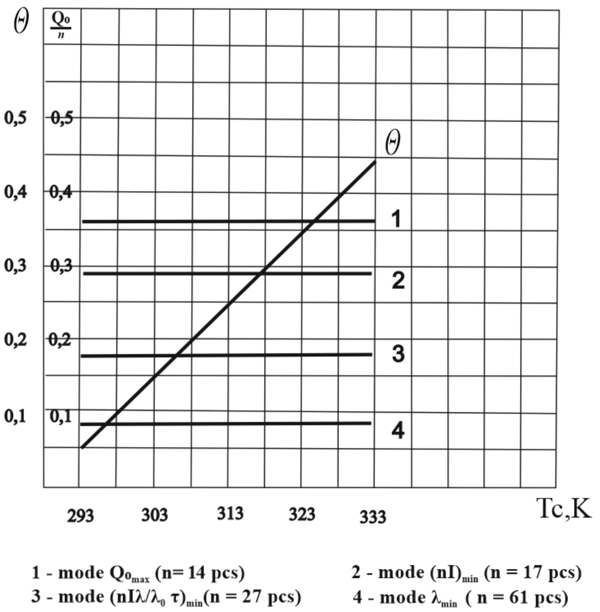

Fig. 5. **Dependence of the relative temperature drop Θ and cooling capacity per thermocouple Q_0/n on the medium temperature T_c for different initial characteristic current operating conditions at T_c = 338K at l/S = 293; K, = 4.5; Q_0 = 0.5W**

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

– the ramp-up time τ is reduced (Fig.6) for the various characteristic current operating modes. The time to steady-state operation τ decreases from mode $\lambda_{\min}$ to mode $Q_{0\max}$ at a fixed ambient temperature T_c. The minimum steady-state operation time $\tau_{\min}$ is ensured in $Q_{0\max}$;

– the amount of energy N input decreases (Fig.7) for the various initial characteristic current operating modes. The minimum amount of energy $N_{\min}$ expended is ensured in $(nI)_{\min}$;

– the required heat dissipation capacity αF of the heat sink (Fig.8) is reduced for the various characteristic current operating modes. The required heat dissipation capacity αF of the heat sink decreases from mode $Q_{0\max}$ to mode $(nI\,\lambda/\lambda_0\,\tau)_{\min}$ at a fixed medium temperature T_c. The minimum heat dissipation capacity $\alpha F_{\min}$ of the heatsink is achieved in $(nI\,\lambda/\lambda_0\,\tau)_{\min}$;

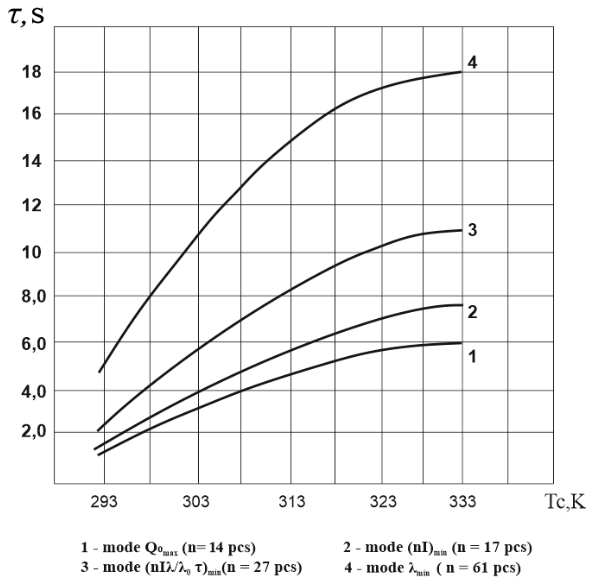

Fig. 6. **Dependence of steady-state time τ on medium temperature T_c for different initial characteristic current modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W**

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

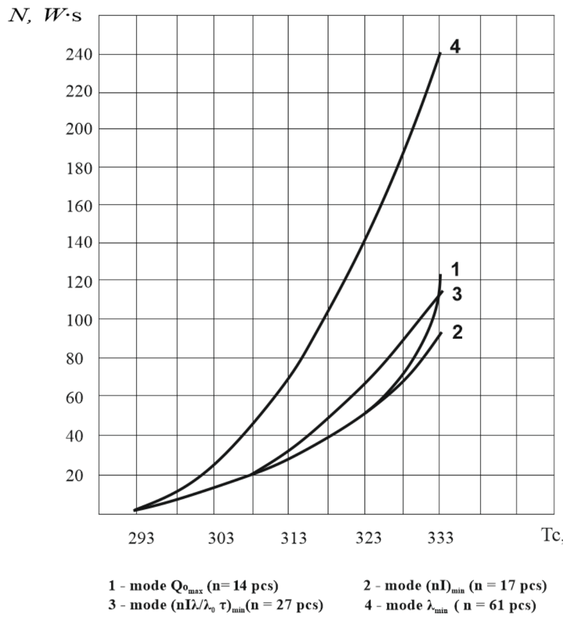

Fig. 7. **Dependence of amount of energy N expended on medium temperature T_c for different initial characteristic current modes at T_c =338K at T_0 =293K; l/S =4.5; Q_0 =0.5W**

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

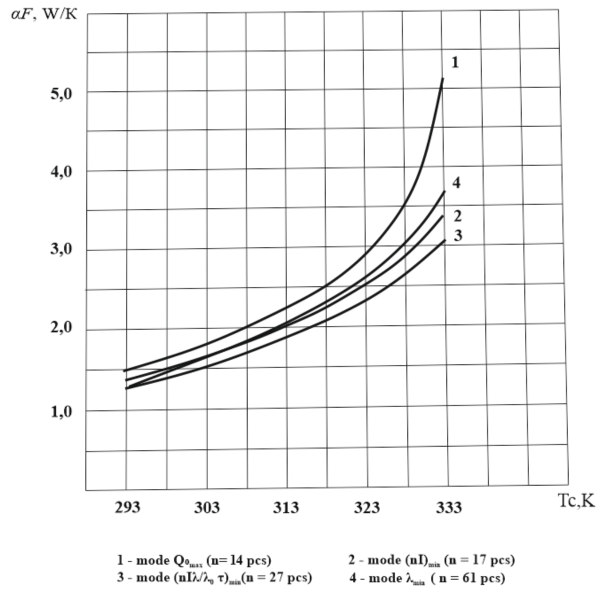

Fig. 8. **Dependence of the required heat dissipation capacity αF of the heat sink on the medium temperature T_c for different initial characteristic current operation modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W; $T - T_c$ = 5K**

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

– the relative failure rate λ/λ_0 decreases (Fig. 9) for the various characteristic operating modes. The relative failure rate λ/λ_0 decreases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed medium temperature T_c. The minimum relative failure rate $(\lambda/\lambda_0)_{\min}$ is ensured in $\lambda_{\min}$;

– the probability P of failure-free operation increases (Fig.10) for various initial characteristic current operating modes. The fault probability P increases from mode $Q_{0\max}$ to mode $\lambda_{\min}$ at a fixed medium temperature T_c. The maximum probability $P_{\max}$ of no-failure operation is provided in $\lambda_{\min}$.

– Fig. 11 shows the dependency of the operating current I and the relative failure rate λ/λ_0 on the ambient temperature T_c for the mode $(nI\,\lambda/\lambda_0\,\tau)_{\min}$ (n=27 pcs.) at T_0=293K, Q_0 =5.0W, l/S =4.5.

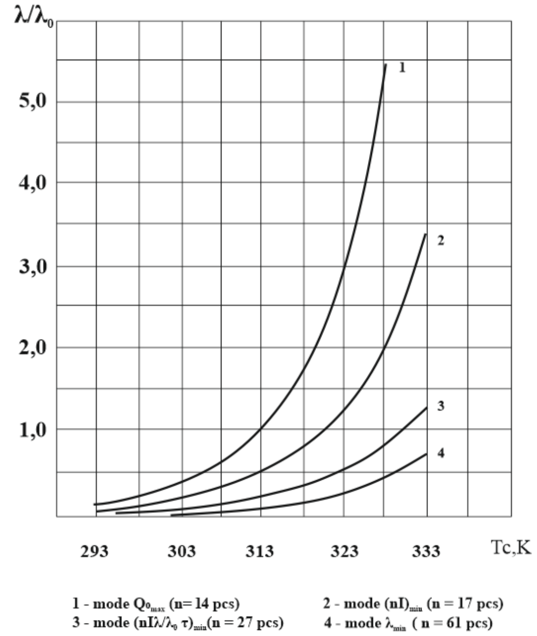

Fig. 9. **Relative failure rate λ/λ_0 dependence on medium temperature T_c for different initial characteristic current modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W; $t = 10^4 h$**

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

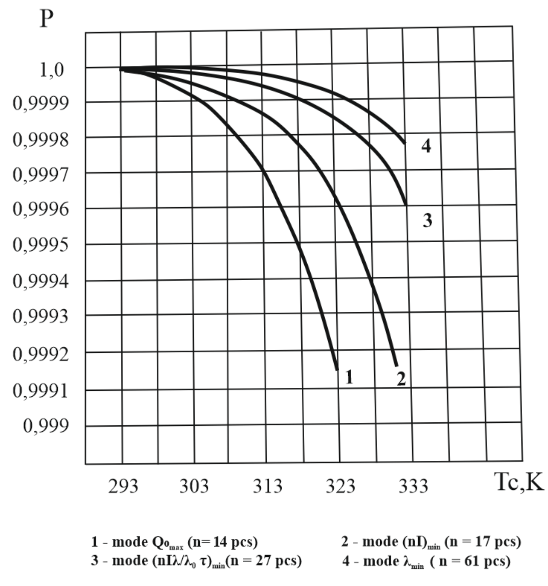

Fig. 10. **Failure probability P dependence on medium temperature T_c for different initial characteristic current operation modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W; $t = 10^4 h$**

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

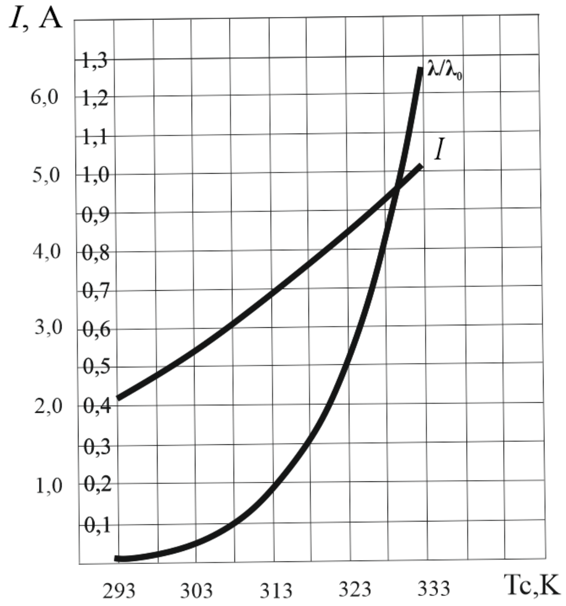

Fig. 11. **Dependence of operating current I, relative failure rate λ/λ_0 on medium temperature T_c for different initial characteristic current operating modes at T_c = 338K at T_0 = 293K; l/S = 4.5; Q_0 = 0.5W**

Source: **compiled by the authors**

DISCUSSION OF ANALYSIS RESULTS

As the medium temperature T_c decreases, the operating current I and the relative failure rate λ/λ_0 decrease.

For example, as the ambient temperature T_c decreases from T_c=333K to T_c=323K, the operating current I decreases from I=5.1A to I=4.6A, i.e. by 16%, and the relative failure rate λ/λ_0 from λ/λ_0=1.3 to λ/λ_0=0.53, i.e. by a factor of 2.45.

With the medium temperature T_c decreasing from T_c = 333K (+60^{0}C) to T_c = 323K (+50^{0}C) at a given cooling level T_0 = 293K, heat load Q_0 = 5.0W and thermocouple branch geometry (ratio l/S = 4.5).

1. For initial characteristic current operation $Q_{0\max}$ (n =14 pcs.):

– the relative operating current B is reduced by 33 %, the operating current I by 31 %, the supply voltage U by 31%, the ramp-up time τ by 3.4 %, the energy N input by 56 %, the required heat dissipation capacity αF of the heat sink by 44% and the relative failure rate λ/λ_0 by 4.9 times;

– the cooling factor E increases by a factor E of 2.2, the probability P of failure-free operation from P=0.9958 to P=0.99914.

2. For the initial characteristic current mode $(nI)_{\min}$ (n=17pc):

– the relative operating current B is reduced by 20 %, the operating current I by 18 %, the voltage drop U by 23.5 %, the ramp-up time τ by 9%, the energy N input by 41 %, the required heat dissipation capacity αF of the heat sink by 24 % and the relative failure rate by a factor λ/λ_0 of 2.6;

– the cooling factor E increases by 56 %, the probability P of no-failure operation from P=0.99888 to P=0.99960.

3. For initial characteristic current operation $(nI\,\lambda/\lambda_0\,\tau)_{\min}$ (n=27 pcs.):

– the relative operating current B is reduced by 19 %, the operating current I by 16 %, the voltage drop U by 20 %, the ramp-up time τ by 11 %, the energy N input by 41 %, the required heat dissipation capacity αF of the heat sink by 22 % and the relative failure rate λ/λ_0 by 2.5 times;

– the cooling factor E increases by 52 %, the probability P of failure-free operation from P=0.99960 to P=0.99984.

4. For the initial characteristic current mode $\lambda_{\min}$ (n=61 pcs.):

– the relative operating current B is reduced by 20%, the operating current I by 19 %, the voltage drop U by 22 %, the ramp-up time τ by 5.5 %, the energy N input by 41 %, the required heat dissipation capacity αF of the heat sink by 30 % and the relative failure rate λ/λ_0 by a factor of 3;

– the cooling factor E increases by 60%, the probability P of failure-free operation from P=0.99977 to P=0.999925.

Thus, by reducing the medium temperature T_c at a given TEC design (n=Const), cooling level Q_0 and geometry of thermocouple branches (ratio l/S) one can significantly reduce the failure rate λ, and, consequently, increase the probability of no-failure operation P, which allows one to control the reliability performance of single stage TEC by simply changing the operating current value I.

CONCLUSIONS

The thermophysical model for estimation of influence of change of temperature T_c of environment on indices of reliability of single stage TEC of various design at given temperature level T_0 of cooling, thermal load Q_0, geometry of branches of thermoelements (relation l/S) for various characteristic thermal modes of operation is developed.

An analysis of the research results has shown that it is possible to control the reliability performance of a single stage TEC of a given design by simply changing the operating current I by changing the temperature T_c of the medium.

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Управління показниками надійності однокаскадного термоелектричного охолоджувача при зміні температури середовища

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АНОТАЦІЯ

Представлено розробку методу керування показниками надійності термоелектричної системи забезпечення тепловими режимами радіоелектронної апаратури, що базується на варіації температури середовища термоелектричних охолоджувачів. Розглянуто математичну модель для дослідження впливу зміни температури середовища на показники надійності однокаскадного термоелектричного охолоджувача за заданого температурного рівня охолодження, теплового навантаження, геометрії гілок термоелементів для різних характерних струмових режимів роботи. Наведено результати розрахунків основних параметрів, показників надійності, динамічних характеристик і здійснено аналіз залежностей для виявлення особливостей процесів керування. Показано, що зі зменшенням температури середовища за заданої конструкції охолоджувачів зменшується величина робочого струму, збільшується холодопродуктивність, зменшується час виходу на стаціонарний режим роботи для різних характерних струмових режимів роботи. Час виходу на стандартний режим роботи зменшується від режиму мінімальної інтенсивності відмов до режиму максимальної холодопродуктивності за фіксованої температури середовища. Мінімальний час виходу на стаціонарний режим роботи забезпечується в режимі максимальної холодопродуктивності. Зазначено зменшення таких значущих для керування показників, як кількість витраченої енергії для різних характерних струмових режимів роботи, необхідної тепловідвідної здатності радіатора, часу виходу на стаціонарний режим. Аналіз результатів досліджень показав можливість керування показниками надійності однокаскадного охолоджувача заданої конструкції за зміни температури середовища за рахунок зміни величини робочого струму. Зміна температури середовища термоелектричного охолоджувача за рахунок зовнішнього забезпечувального пристрою дає змогу варіювати показниками надійності та знайти компроміс між надійністю, динамікою та холодопродуктивністю системи забезпечення теплових режимів.

Ключові слова: Термоелектричний охолоджувач; тепловий режим; температура середовища; динамічні характеристики; керування показниками надійності

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