STUDY OF DEVICE'S MAXIMUM OVERHEAD DEPENDENCE FROM ITS SIZES AND INSTALLATION DENSITY

A. Sinotin, S. Sotnik, K. Khrustalev, R. Allakhveranov, O. Chala

Abstract: A number of studies have been carried out, during which the dependencies of the device's maximum overheating on its dimensions and mounting density have been determined. In the paper such dependences graphs are presented: initial parameter values on the heated zone dimensions and surface heat transfer intensity, taking into account the effective thermal conductivity in the absence of heat pipes in the gas filler; temperature values at the central point of the heated zone in the absence, presence and when the thermocouples are delivered to the casing. As a result, it is determined that the transition to the construction with the form of a square "beam" ensures the most effective minimization of the shape parameter. The minimization degree increases with increasing device cooling system efficiency.

Key words: heating, apparatus, anisotropy, thermal conductivity, heat transfer.

Introduction

Modern apparatus design, along with the electrical circuits development, requires a strict account of the temperature regime for future design. This raises task for designer to perform thermo physical design at all stages of development of reliable, economical, small-sized radioelectronic equipment (REE), which consists of microsystem equipment products (MSE).

MSE products represent an innovative class of the most complex integrated electronic products, without the development of which it is impossible to build promising robotic and "intelligent" systems and REE complexes for various purposes [1].

An attempt at an empirical search for an acceptable design variant becomes economically unjustified.

Incorrect placement of one element can be easily identified and eliminated in course of finished structure temperature tests (verification calculations).

Elimination of errors in the overall elements layout requires additional unproductive expenses for processing the entire structure of the apparatus, therefore, designer faces task of ensuring normal thermal conditions of elements at all device design stages.

The purpose of study is to determine nature of apparatus dimensions influence on temperature regime of designed structure.

1. Determination of apparatus design "initial parameter"

Thermophysical design is carried out on the base of multiple calculations for different values of parameters, that is, the trial and error method is used.

We shall carry out investigations of heated zone shape influence on maximum apparatus overheating.

So, effect of apparatus volume on its maximum overheating can be expressed in terms of so-called initial parameter F_0.

$$F_0 = \frac{P_0}{\vartheta_0} \cdot \frac{1}{4\lambda \cdot \sqrt[3]{V}} \cdot \frac{0{,}82 A_0^3}{3\mu_0^2}, \qquad (1)$$

$$B_{io} = \frac{K_0}{\lambda_0} \cdot \frac{1}{2} \cdot \sqrt[3]{V}, \qquad (2)$$

where P_0 – total heat power, W;

ϑ_0 – maximum permissible device overheating, degree;

λ_0 – effective thermal conductivity in the absence of heat pipes with gas filler, W/m.deg;

V – volume of heated zone, m^3;

A_0, μ_0 – amplitude and eigenvalues of the characteristic equation for B_{io};

K_0 – average surface heat transfer coefficient W/m^2 . deg;

B_{io} – Bio criteria.

The initial parameter F_0 characterizes the thermal regime of following REE design:

- heated zone has form of a cube

$$\xi_{X_0} = \xi_{Y_0} = \xi_{Z_0} = 1, \qquad (3)$$

where $\xi_{I_0} = 2l_{mii} / 2l_i$, at $i = X, Y, Z$;

- anisotropy in terms of thermal conductivity in volume and heat transfer on surfaces is absent, then

$$\lambda_X = \lambda_Y = \lambda_Z = \lambda_0,$$

$$K_X = K_Y = K_Z = K_0. \quad (4)$$

- conductive heat pipes are absent, then

$$\lambda_{max} = \lambda_0. \quad (5)$$

- power of heat sources is distributed evenly.

2. The main part

Fig. 1 shows the dependence of parameter $F_0 \cdot \vartheta_0 / P_0 \cdot 10^2$ on volume of device heated zone and heat transfer coefficient K_0 characterizing the surface cooling system for apparatus with effective thermal conductivity $\lambda_0 = 0{,}2$ W/m·Deg [2].

As follows from graphs (Fig. 1) initial parameter F_0 can be minimized by reducing the ratio P_0 / ϑ_0, increasing the volume of heated zone V, and intensity of surface heat transfer K_0.

Let's consider each factor separately.

Reducing the ratio P_0 / ϑ_0 causes certain requirements for development of apparatus electrical scheme.

In Fig. 1 M stands for montage.

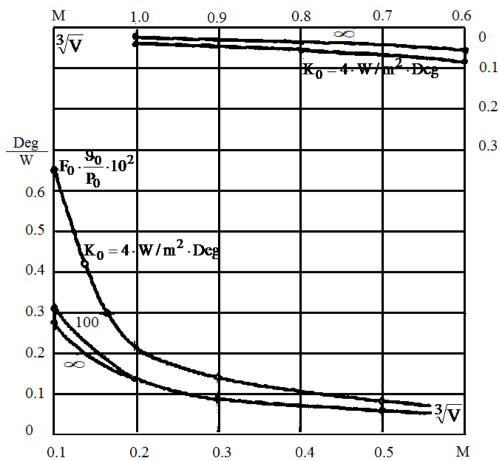

Fig. 1. Dependence of initial parameter on heated zone dimensions and intensity of surface heat transfer K_0 at λ_0 =0,2 W/m . Deg

For realization of circuit solutions, it is expedient to choose the element base with the lowest power consumption and materials with high temperature resistance.

If it is necessary to use separate elements with a small permissible overheating temperature ϑ_0, it is advisable to separate these elements into an independent group in order not to complicate the provision of a given thermal regime of device design as a whole. This remark is very important to take into account when choosing the element base of electrical circuit, since after assigning the circuit to designer, it is not able to influence the power dissipation factor and circuit elements temperature resistance.

The analysis of dependencies (Fig. 1) shows that for single-block cubic designs of apparatus with a size $\sqrt[3]{V} \geq 0{,}5$ m, minimization of initial parameter F_0 due to increase in heated zone volume (elements density) and transition to a more intensive system of surface cooling $K_0 = \infty$ becomes practically impossible.

Conversely, for structures of size $\sqrt[3]{V} \leq 0{,}5$ m, volume increase and growth K_0 lead to a threefold decrease F_0 at $\sqrt[3]{V} = 0{,}1$ m and by 50% at $\sqrt[3]{V} = 0{,}3$ m due to a change K_0 Sfrom 4 W/m^2.Deg to ∞.

Almost at $K_0 \geq 100$ W/m^2.Deg, limiting case is now, that is, for devices with gas filling (with low effective thermal conductivity $\lambda_0 = 0{,}2$ W/m.Deg), it is inappropriate to use liquid and other more effective surface cooling systems.

The limiting minimization F_0 can be realized due to use of forced convective air cooling (α = 10 - 100 W / m. Deg) [3].

Heat transfer coefficient

$$K_0 = \frac{K' S_k / S}{1 + K' S_k / \alpha S}, \quad (6)$$

where K' – coefficient of heat exchange through gas layer from heated zone to casing, W/m^2.Deg;

α – coefficient of heat exchange between the casing surface and environment, W/m^2.Deg;

S_k – surface area of apparatus casing of the apparatus, m^2;

S – surface area of heated zone, m^2.

Analysis of expression (6) and heat transfer coefficients values for different types of cooling systems [3] allows us to determine two ways of increasing K_0 for minimizing parameter F_0 and synthesizing design with a specified thermal regime for maximum overheating.

The first way is purely constructive for small values K_0, that is, for radioelectronic devices designed to function under conditions of natural cooling by air.

Calculations of a large number of device designs [4] showed that there is an equality of conductivity between heated zone and casing, as well as with the environment:

$$K' \cdot S \approx \alpha \cdot S_k . \quad (7)$$

After substituting (7) into (6), we get, $K_0 = \alpha \cdot S_k$ that is, the application of casing practically reduces the efficiency of surface cooling by half.

When the device housing is combined with the heated zone, $(S_k = S)$, $K' \to \infty$ and $K_0 = K$.

Thus, in a purely constructive way, by combining the casing of the apparatus with the heated zone, it can be doubled (Fig. 2). Thus, in a purely constructive way, by combining the apparatus casing with heated zone, K_0 can be doubled (Fig. 2).

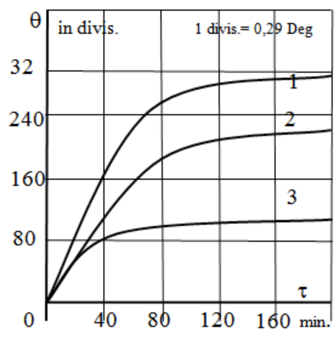

Fig. 2. The value of temperature at central point of heated zone

In Fig. 2. Graphs:

1 – in the absence of heat;

2 – in the presence of heat;

3 – when drains are placed on the casing.

In this case, it is necessary to ensure good thermal contact between heated zone and casing, for example, using high-conductivity pastes in junctions between boards (chassis), casing faces, etc.

The considered method is most effective when it is required to keep tightness (dustproof) of equipment.

You can also use another constructive way: to reduce the effect of casing on heat sources intensity due to violation of tightness and to ensure direct contact of heated zone with cooling air through the perforation (blinds) holes.

Then, for K_0 the first approximation, expression takes the form

$$K_0 = K_0 \cdot (1 + S_{per} / S_k), \quad (8)$$

where S_{per} – perforation area, m^2;

K_0 – is given by (8) at $S_{per} = 0$.

The ratio S_{per} / S_k is called perforation coefficient.

A more rigorous account of perforation is given in [3].

Practically already at $S_{per} / S_k = 0{,}5 \div 0{,}6$ a value K_0 close to K_0 that is, limiting effect of minimization F_0 is reached.

The considered constructive methods do not allow to significantly change the heat transfer coefficient K.

For a significant change in intensity of heat transfer on heated zone surface, a transition from natural to forced surface cooling by blowing air is necessary, that is, additional changes in apparatus design are required. In this case, according to equation (2), it is necessary either to simultaneously increase the heat transfer intensity between heated zone and casing (K'), casing and surrounding environment (α), or pre-align the casing with heated zone $(K' \to \infty)$. Otherwise, growth K_0 will be insignificant, despite a significant increase α.

Thus, in second minimization path due to increase K_0, a transition to a new cooling system is envisaged, with a pre-combination of casing with heated zone, especially in tightly assembled structures.

The increase in heated zone volume due to reduction in density of elements arrangement is in contradiction with requirement to minimize structure dimensions, so it can be applied only in case where there are no strict limitations on design dimensions in technical assignment.

In practice, a change in volume by a factor of 8 (in the section $\sqrt[3]{V} < 0,5$m) leads to a threefold decrease F_0 in $K_0 = 4$ W/m^{2}Deg and twice as much $K_0 = \infty$ (Fig. 1). Such a change in volume can be achieved by switching from mounting a high density $(\eta_i \geq 1)$ to mounting a small one $(\eta_i \approx 1)$.

Conclusion

1. Effective minimization of initial parameter can be carried out for structures of devices with a linear size less than 0.5 m, due to the transition to a low density or an increase in efficiency of surface cooling system. For structures with a linear dimension greater than 0.5 m, minimizing the initial parameter is practically impossible.
2. It is established that transition to construction in form of a square "beam" ensures the most effective minimization of shape parameter. The degree of minimization increases with increasing efficiency of device cooling system.

Bibliography

[1] **I. Sh. Nevludov, V. A. Palagin, O. O. Chala.** Tehnologii mikrosistemnoy tehniki. *Tehnologiya priborostroeniya,* #2, 2014, S. 7-10.

[2] **G.N. Dul'nev, N.N. Tarnovskiy.** *Teplovyye rezhimy elektronnoy apparatury.* L.: Energiya, 1971, 248 s.

[3] **V.V. Semenets', A.M. Sinotin, T.A. Kolesnikova.** *Proyektuvannya odno blokovikh radioyelektronnikh priladiv iz zadanim teplovim rezhimom.* Kharkiv: KHNURE, 2006, 172 s.

[4] **I. M. Mayko, A. M. Sinotin.** Eksperimentalnoe opredelenie effektivnoy teploprovodnosti nagretyih zon radioelektronnyih apparatov. *Voprosyi radioelektroniki,* # 2, 1972, S. 13-17.

Information about the Authors:

Anatoly Sinotin, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. Doctor of Science (Engineering), professor of Computer-Integrated technologies, automation and Mechatronics.

Svetlana Sotnik, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. Candidate of Science (Engineering), Associate professor of Computer-Integrated technologies, automation and Mechatronics.

Kirill Khrustalev, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. К.т.н., Ph.D., Candidate of Science (Engineering, assistant of Computer-Integrated technologies, automation and Mechatronics.

Rauf Allakhveranov, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. Candidate of Science (Engineering), Associate professor of Computer-Integrated technologies, automation and Mechatronics.

Olena Chala, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. Assistant of Computer-Integrated technologies, automation and Mechatronics.

Web address: 61166, Kharkiv National University of Radio Electronics, Nauki Avenue, 14. Phone: (057) 7021-486.

e-mail address: svetlana.sotnik@nure.ua