Artículo de investigación

Simulation of thermal conditions of a radio-electronic block of a cassette design

Моделирование тепловых режимов радиоэлектронного блока кассетной конструкции

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Written by:
Kamil Z. Khairnasov[265]
https://www.scopus.com/authid/detail.uri?authorId=57201774042

Abstract

The modelling and study of the thermal conditions of the electronic unit of the cassette design installed in the open compartment of the spacecraft on a thermal stabilization platform operated in a vacuum is considered. One of the main issues of heat removal from electronic components is the effect of the characteristics of the intermediate layers of a multilayer printed circuit board on effective heat dissipation. Effective heat removal means determining the thickness of the intermediate copper layer, which significantly affects the heat removal and determination of the thickness of which does not lead to heat removal, but only increases the mass characteristics of the electronic device, which is one of the main parameters in aerospace engineering. The problem is solved by the finite element method. The convergence of the results was checked by thickening the grid of finite elements. If the results of the previous and subsequent, partitions differ by no more than 2-3%, then it is considered that the results of the calculations are valid. Thermal calculation of the cassette, performed by the finite element method, and analysis of the results showed that the thickness of the intermediate copper layers nonlinearly affects the temperature distribution in electronic components, with the greatest effect being observed when the thickness of the intermediate copper layer less than 175 microns. When the thickness of the intermediate copper layer is more than 175 µm, heat removal is ineffective in terms of weight characteristics. The calculation results illustrated by the figures of the distribution of the temperature field during module operation are presented.

Keywords: Conduction, electronic devices, finite element method, mathematical modeling, thermal regime.

Аннотация

Рассмотрено моделирование и исследование теплового режима электронного блока конструкции кассеты, установленного в открытом отсеке космического аппарата на платформе термостабилизации, работающей в вакууме. Одним из основных вопросов отвода тепла от электронных компонентов является влияние характеристик промежуточных слоев многослойной печатной платы на эффективное рассеяние тепла. Эффективный отвод тепла означает определение толщины промежуточного медного слоя, который существенно влияет на отвод тепла, и определение толщины которого не приводит к отводу тепла, а лишь увеличивает массовые характеристики электронного устройства, которое является одним из основных параметров в аэрокосмической технике. Задача решается методом конечных элементов. Сходимость результатов проверялась путем сгущения сетки конечных элементов. Если результаты предыдущего и последующих разбиений различаются не более чем на 2-3%, то считается, что результаты расчетов являются действительными. Тепловой расчет кассеты, выполненный методом конечных элементов, и анализ результатов показали, что толщина промежуточных слоев меди нелинейно влияет на распределение температуры в электронных компонентах, причем наибольший эффект наблюдается при толщине промежуточного слоя меди. менее 175 мкм. Когда толщина промежуточного медного слоя составляет более 175 мкм, отвод тепла неэффективен с точки зрения весовых характеристик. Представлены результаты расчетов, иллюстрируемые рисунками распределения температурного поля при работе модуля.

Ключевые слово: математическое моделирование, метод конечных элементов, проводимость, тепловой режим, электронные устройства.

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[265] PhD of Technical sciences, Associate Professor, Department of Instrument Engineering Technology, Moscow Aviation Institute (National Research University), 125993 Volokolamskoe highway 4, Moscow, Russia.

Introduction

Electronic devices of aviation equipment must satisfy the following properties: small dimensions and mass characteristics. Therefore, reliable calculation of the thermal regimes of electronic devices of aviation technology is important. Bearing in mind the consequences of the failure of devices in flight.

The most important tool for assessing the thermal state of an aircraft instrument in the environment of an aircraft is the mathematical modelling of the thermal conditions of the components of on-board electronic equipment. Therefore, the reliability of mathematical models and the results of modelling heat transfer processes in structures with a new electronic component base are practical guidelines for the thermal design of equipment. There are several approaches to solving the problem of heat dissipation in multilayer printed circuit boards. One of the most effective methods is to arrange heat-transfer layers in a multilayer printed circuit board made of materials with a high degree of heat transfer: copper, aluminium, stainless steel, etc., which leads to temperature removal to the device case. At the same time, it is necessary to identify the most optimal thickness, physic-mechanical characteristics of the heat-removing layers. Bearing in mind that the material of the heat-releasing layers has various physical and mechanical characteristics, a large specific gravity, and an unjustified increase in thickness can lead to an increase in the mass of the product.

Electronic devices used in aviation must have enhanced reliability characteristics, due to the large consequences of their failure during operation (Medvedev, 2005; Lucas, 1994; Levashkin, Ogin, Vasilyev, 2019, Vantsov, Vasilyev, Medvedev, Khomutskaya, 2019). One of the factors ensuring the reliability of electronic devices used in aeronautical engineering is reliable mechanical and thermal calculation. Exceeding the permissible thermal operating conditions of electronic components leads to the failure of these elements and ultimately to the failure of the electronic device with unpredictable consequences during the flight. One of the factors affecting the heat sink in multilayer printed circuit boards, which are of great use in aircraft devices, is the thickness and material characteristics of the heat sink layers. A significant number of works have been devoted to heat removal issues (Khairnasov, 2013; VintrouLaraqi, Bairi, 2012; Costa, Vlassov, 2013; Funk, Mengüç, Tagavi, Cremers, 1992; Muzychka, Yovanovich, Culham, 2006; Rinaldi, 2006; Muzychka, Bagnall, Wang, 2013; Monier-Vinard, Laraqi, Dia, Nguyen, Bissuel, 2013; Shabany, 2002; Schacht, Wunderle, May, Michel, Reichl, 2008; Dede, Nomura, Lee, 2015).

At the same time, the issue of optimal thickness, thermal characteristics, location and structure of heat-removing layers in multilayer printed circuit boards has not yet been resolved. An unjustified increase in the thickness of the heat-removing layers affects the mass characteristics of aviation devices, which are of great importance in aviation.

In this paper, we consider the question of the optimal thickness and materials for heat sink layers in multilayer printed circuit boards.

Electronics as a part of modern spacecraft are one of the most important factors for progress. The level and quality of its execution largely determines the competitiveness of rocket and space technology in the military and civilian sectors of the economy (Funk, Mengüç, Tagavi, Cremers, 1992; Muzychka, Yovanovich, Culham, 2006). As a rule, every three to five years, the electronic component base is modified structurally and functionally and integrated into more complex structures.

In engineering practice, it is often difficult to investigate the suitability of a new electronic component base, especially imported and designed for operation in a vacuum. In the electronic equipment for remote sensing of the Earth, containing a huge amount of memory and information transmitted in the shortest possible time, it is necessary to create innovative non-traditional structural and technological solutions both in power structures of radioelectronic units and in multilayer boards, the number of which can reach several dozen layers especially when using surface mounting domestic and foreign electronic component base, besides having a high cost (Muzychka, Bagnall, Wang, 2013; Monier-Vinard, Laraqi, Dia, Nguyen, Bissuel, 2013).

The most important tool for assessing the thermal state of an electronic component base in a spacecraft environment is mathematical modelling of the thermal state of the components of an onboard electronically device. This circumstance is also due to the fact that it is usually postponed to carry out the necessary and reliable testing of newly created equipment due to the limited development time and its means for later periods when it is very difficult to eliminate the revealed remarks. Therefore, the reliability of mathematical models and the results of modelling the processes of heat transfer in designs with a new electronic component base are practical guidelines for thermal design of equipment (Dede, Nomura, Lee, 2015).

In this paper, we study the thermal conditions of an onboard electronic device designed to work in the open compartments of full-size or small spacecraft, since they ultimately determine the quality and survivability of new types of basic electronic components (Godin, Khairnasov, Sokolsky, 2004; Khairnasov, 2013).

As an illustrative example, consider the thermal mode of an electronic unit of a cassette design, hereinafter referred to as a cassette, which is the basis for electronic components operating in a vacuum. Operating conditions are characterized by the following parameters:

- Cassette is installed in the unpressurized compartment, the vacuum is from 10-2 to 10-6 mm Hg. (10-6 mm Hg were taken in calculations);
- Temperature of the installation surface of the spacecraft (temperature of thermostatically controlled thermal baths of spacecraft) is maintained between minus 10°C and plus 40°C (plus 40°C was taken in the calculations);
- Temperature of structural elements inside unsealed spacecraft compartment, i.e. environment surrounding device (cassette) varies in the range of ± 50°C (plus 50°C was taken in the calculations); continuous operation modes; generated power of 42 watts.

The parameters of the board-frame: housing material aluminum (thermal conductivity 120 W/mK), overall dimensions: 285•150•30 mm, overall dimensions of the base: 312•30 mm, thickness of two copper intermediate layers 175 µm each.

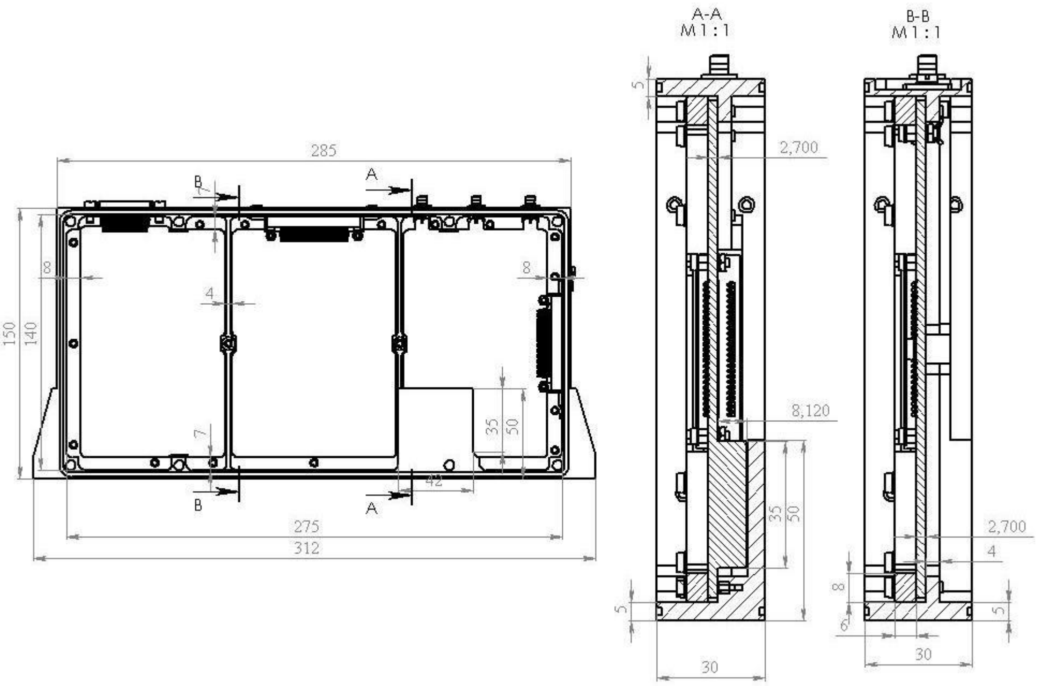


Figure 1. Drawing of a cassette case with a multi-layer printed circuit board

Theoretical basis

The cassette is installed in an unpressurized compartment on a thermostatically controlled thermocables spacecraft with good thermal contact through a heat-conducting gasket or paste (paste was used in the calculations) (Medvedev, 2005; Levashkin, Ogin, Vasilyev, 2019).

The cassette consists of the board-frame with a cut-out bottom, in which a printed circuit board is inserted. The board is installed in the plate-frame on the paste 131-179 and is pressed against the pressure plates. The heat flux from the electronic components spreads across the board due to copper layers 175 microns thick and plated holes, and then flows along the copper edges of the plate to the cassette case. Figure 2 shows the temperature distribution for one of the cases considered. Thermal contacts were filled with heat-conducting material Elazil type 137-182 or paste (Shabany, 2002; Schacht, Wunderle, May, Michel, Reichl, 2008).

Methodology

Currently, there are a large number of programs that allow you to perform thermal calculation of electronic modules, with the output of the results in graphs, tabular form and figures (Lucas, 1994). There are several approaches to solving thermal problems of electronic devices of aircraft: analytical, graphic and numerical. The most complete picture of the temperature distribution, mutual influence of the thermal fields of electronic components, full consideration of the boundary conditions allows us to make a numerical method: finite element method (Vantsov, Vasilyev, Medvedev, Khomutskaya, 2019).

The problem is solved by the finite element method. The cassette (Figure 1 and 2) was modelled by 8-node cubic finite elements of three-dimensional conductivity. The equation of linear static thermal conductivity is:

$$Q = C \times T$$

where C is the conductivity matrix, depending on the material (W / ºC), T is the unknown temperature in the nodes to be determined (ºC), Q is the heat source, defined as the load (Watt).

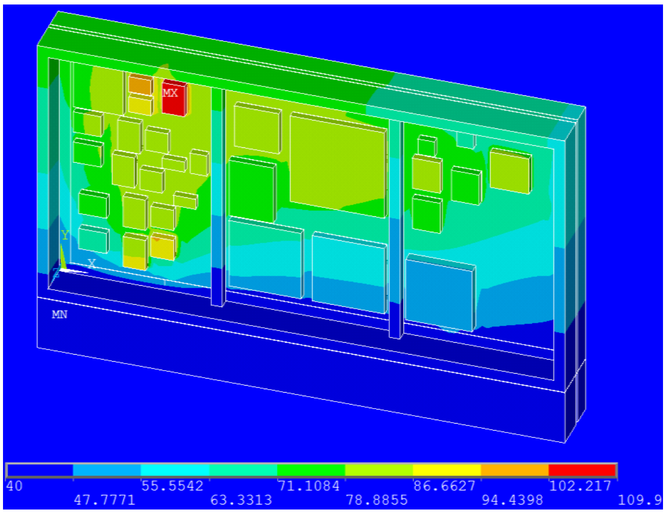
As an external load applied to the boards, the intensity of the distributed heat per unit area applied to the edges of the structural elements (W / mm2) and the intensity of the distributed heat per unit volume (W / mm3), as well as the external temperature applied to the elements of the thermostatically controlled thermal board (°C).

As a result of the study, the temperature in the nodes of the final elements was determined. The total number of finite elements of the partition was 75690. The accuracy of the obtained calculations was checked by thickening the grid of finite elements. The calculation error when splitting into 96525 finite elements and the adopted splitting scheme was ~ 2%. This discrepancy between the results allows us to state that the calculation results converge and take as a basis the previous partition into finite elements (Vintrou, Laraqi, Baïri, 2012; Costa, Vlassov, 2013). The convergence of the results implies the reliability of the results obtained within the computational error of solving large systems of equations.

Results

As a result of the study, a simulation of the cassette block with electronic components was carried out. The device was approximated by finite elements, including a multilayer printed circuit board having thin layers of about 18 microns.

Boundary conditions and dissipated powers of the electronic components were applied. The solution of an inhomogeneous system of linear equations is made. A picture of the temperature distribution (Figure 2) and the temperature distribution in the heat sink layer located in the multilayer printed circuit board (Figure 3) are obtained. The dependence of the maximum temperature on the thickness of the intermediate copper layer is also obtained (Table 1).



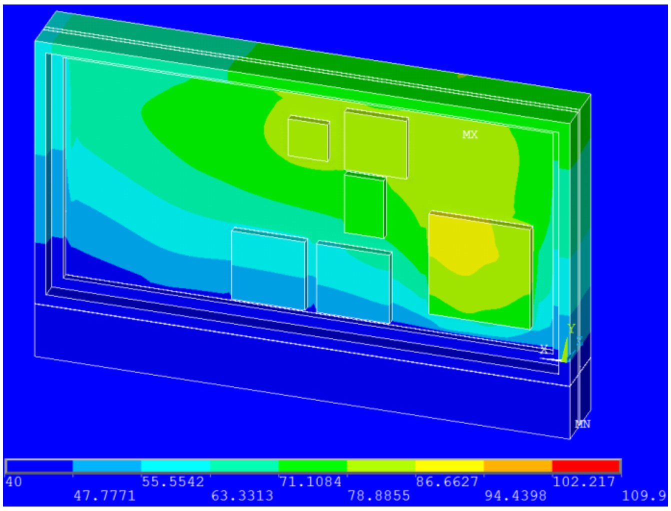


Figure 2. Example of visualization of simulated results. Temperature distribution in the cassette. Front and back view. Temperature from plus 40.0 to plus 109.9 ° C

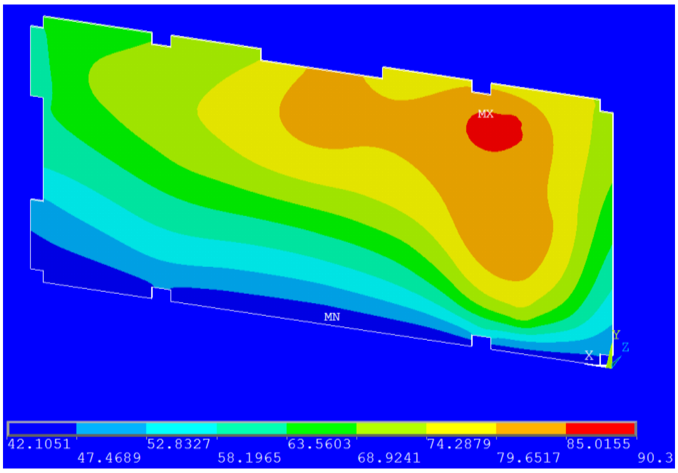


Figure 3. Temperature distribution in the copper layers of the board. Temperature from plus 40.0 to plus 90.3 ° C

The Table 1 shows the results of calculating the maximum temperature of an aircraft instrument by the thickness of the intermediate heat sink layer, which shows that this temperature depends on the thickness of the heat sink layer. At a certain thickness of this layer, this dependence sharply decreases. This thickness was taken as optimal according to the results of modeling the thermal state of instrument.

At the bottom of the figures nine temperature gradations of elements from the minimum - indicated by the MN index to the maximum - designated by the MX index are shown.

Table 1. Dependence of the maximum temperature on the thickness of the intermediate copper layer

Thickness of the copper layer of the board, μm	5	20	40	60	105	175	235	300	355	450
Maximum temperature of electronic components, ° C	394	217	159	134	119	110	105	101	98,6	95,1

The calculation and analysis given in the Table 1 shows that the maximum temperature up to 105-175 μm significantly depends on the layer thickness; for a layer of more than 175 μm, the temperature drops slightly.

Conclusion

As a result of the study, a simulation of the cassette block with electronic components was carried out. The device was approximated by finite elements, including a multilayer printed circuit board having thin layers of about 18 microns.

Boundary conditions and dissipated powers of the electronic components were applied. The solution of an inhomogeneous system of linear equations is made. A picture of the temperature distribution (Figure 2) and the temperature distribution in the heat sink layer located in the multilayer printed circuit board (Figure 3) are obtained. The dependence of the maximum temperature on the thickness of the intermediate copper layer is obtained (Table 1).

Thermal calculation of the cassette, performed by the finite element method, and analysis of the results showed that the thickness of the intermediate copper layers nonlinearly affects the temperature distribution in electronic components, with the greatest effect being observed when the thickness of the intermediate copper layer less than 175 microns.

When the thickness of the intermediate copper layer is more than 175 μm, heat removal is ineffective in terms of weight characteristics. The results of the study can be applied in the design and manufacture of electronic devices for aircraft containing multilayer printed circuit boards with heat-removing layers in the body of the printed circuit board. The obtained optimum characteristics of the thickness of the heat-removing layers will allow making the development of electronic components with optimal thermal characteristics.

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