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METHODOLOGY OF CALCULATING THE THERMAL REGIME OF TERMINAL EQUIPMENT FOR AIR TRAFFIC CONTROLLERS' COMMUNICATION SYSTEMS

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Abstract. The problem of increasing the heat sink of terminal equipment of voice communication control systems for air traffic controllers is being solved. Noise standards established for the workplace of an air traffic controller, together with reliability requirements, do not allow the use of active cooling for cooling of the terminals. A method of thermal calculation of terminal housings with passive cooling has been developed. The calculation of the heat-stressed state of the communication terminal housing has been performed. On the basis of finite element modeling, design changes are predicted that can significantly reduce the temperature of the terminal processor, thus extending the equipment service life. The adequacy of the obtained results was verified using experimental design and a full-scale experiment based on a full-scale specimen of the terminal.
Keywords: voice communication control systems, communication terminals, thermal calculations, finite element model, passive cooling.

One of the features of digital voice communication control systems (VCCS) [1] used for air traffic control is the low noise level of terminal equipment. Noise standards established for the workplace of an air traffic controller should not exceed 50 db. High requirements for the reliability of the VCCS determine their architecture. The most reliable is the combination of a network distributed architecture and a decentralized terminal architecture. Such a structure assumes that the functions of establishing a telephone and radio connection and managing this connection (including processing speech and signal information) are performed by individual terminal processors and interface equipment involved in this connection. A significant amount of computing operations performed by terminal equipment causes a significant CPU load on the terminal motherboard, which leads to heat emissions equal to about 100 watts at each terminal. At temperatures above 60 °C, processor performance begins to decline sharply and the probability of hardware failure increases. Therefore, efficient cooling is required for stable operation of the processor. The life of terminal equipment is at least 10 years. This condition, combined with the requirements of a low noise level, does not allow the use of active devices (fans, Peltier elements, etc.) to cool the terminal processor. Water cooling is expensive and

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unreliable. Thus, the best solution for this type of device is passive cooling. Passive cooling determines the specific design features of the housings:

- the use of aluminum or copper radiators with a large heat sink area;
- application of thermal interfaces between housing parts;
- the use of thin-walled structures, in some cases made of perforated metal, to create convective heat exchange with the external environment.

Structurally, the cases are made in the form of a monoblock (Fig. 1). The outer part of the case is made of plastic. The internal elements of the housing are made of sheet metal. The original design used a standard motherboard radiator. The heat from the radiator was partially transferred to the metal elements of the housing, and partially dissipated in the internal volume of the housing, and then with the help of convective heat transfer was discharged through the perforated walls into the atmosphere.

Fig. 1. General view of the communication terminal

Such a solution has both a number of advantages and a number of disadvantages. The main advantage is the beautiful design of the product. All elements involved in the heat sink are located inside the plastic case and do not affect the appearance of the terminal. Another advantage is that the electronic components of the housing are attached only to the metal elements of the housing. This makes it possible to easily modify the design of the inner part of the housing when changing electronic components without changing the design of the plastic shell, the manufacture of which requires the use of expensive molds. The disadvantage of this design is that it does not provide sufficient heat removal to the external environment. The main source of heat generation is the motherboard processor. From the processor, heat passes to the radiator and after in turn it partially passes through the thermal interfaces to the metal parts of the housing, and partially dissipates through convection into the internal volume of the housing. Then the heat is dissipated through the ventilation holes in the plastic housing to the external environment. In the upper part of the housing there is a 12” matrix, which makes it difficult for convection heat exchange, preventing hot air from rising up. Heat exits the block only through the ventilation holes in the rear and sides of the housing. At the same time, the space in the processor zone is practically not ventilated. The efficiency of heat removal from the radiator through thermal interfaces is also low. The temperature difference between the radiator and the parts mated to it according to the measurement results is at least 30°C. This is due to the high thermal resistance between the radiator and the mating parts. Due to these factors, the temperature of the processor at 80% load is approximately 70°C (Fig. 2), and the current service life of the motherboard is 5 years with a claimed product life of 10 years. Therefore, the task of reducing the temperature of the processor is relevant.

Fig. 2. Temperature distribution on the surface of the motherboard.

The objectives of this study are to develop a methodology for calculating communication terminals with passive cooling and solving the problem of reducing the processor temperature for a specific terminal using the developed methodology. Quite enough works have been devoted to the thermal calculation of electronic devices [2,3,4,5]. However, the specific design of terminal devices with passive cooling requires a separate study. The complexity of the geometric and thermophysical characteristics of the terminal, a significant number of thermal interfaces and body parts makes it impossible to use analytical calculation methods. The finite element method was used to calculate heat transfer in the body parts and at the joints of the parts, as well as the finite volume method was used to calculate convective heat transfer inside the body. The following are the main relations used in the implementation of numerical algorithms.

The monoblock design assumes participation in the heat exchange of all body parts. The heat transfer inside the individual parts of the terminal obeys the Fourier law. It is generally assumed that heat exchange occurs between isothermal surfaces. The heat flux P transmitted between adjacent isothermal surfaces is equal to

$$P = \frac{\lambda S}{l}(t_1 - t_2), \quad (1)$$

where λ is the coefficient of thermal conductivity of the material, S – area of the average isothermal surface, t_1, t_2 are the temperatures of adjacent isothermal surfaces, $l=x_2-x_1$ is the distance between isothermal surfaces. Table 1 shows the thermal conductivity coefficients of the materials used in the construction of the housing.

Table 1

Material	**λ, W/(m•K)**
Aluminum	170
Copper	380
Steel	50
fiber-glass plastic	0,3

The heat exchange of monoblock parts with the environment is described by Newton's law. The total heat flux given by the isothermal surface S to the medium due to convection is equal to

$$P_k = \alpha_k S(t_1 - t_2), \quad (2)$$

where α_k is the coefficient of convective heat transfer. α_k - depends on a set of parameters characterizing the surface and the medium. Numerical methods are used to determine α_k.
The most difficult task is to determine the thermal conductivity in the contact area of the terminal parts. Thermal resistance of the contact

$$R_c = \frac{P}{\Delta t_c} = \frac{1}{\sigma_m + \sigma_c}, \quad (3)$$

where P is the heat flow flowing through the contact; Δt_c is the temperature difference of the contacting surfaces; σ_m is the thermal conductivity determined by the actual contacts; σ_c – thermal conductivity of the medium.
Specific (area-related) resistance of the actual contact

$$R_{M.spec.} = \frac{\varphi}{2.12\lambda_M \eta} 10^{-4}\ m^2K/W \quad (4)$$

where φ is the coefficient of contraction of the heat flow to the spots of the actual contact, λ_M is the equivalent coefficient of thermal conductivity of the actual contact; n is the relative area of the actual contact. n, φ are determined using empirical data.

$$\frac{\eta}{\varphi} = \left(\frac{pB}{E}\right)^{0,8}, \quad (5)$$

where p is the specific pressure in contact; B is the coefficient characterizing the geometric properties of the surfaces; E is the modulus of elasticity of the material

Thermal conductivity of the interlayer of the contactless medium $\sigma_{\text{c}.spec.} = \lambda_{\text{c}}/\delta_{equ}$, where λ_{c} is the thermal conductivity coefficient of the medium, δ_{equ} is the equivalent distance between the contacting surfaces.

Thermal conductivity of the contact

$$\sigma_{\text{c}} = \left(\frac{1}{R_{\text{м}.spec.}} + \sigma_{\text{c}.spec.}\right) S_{\text{c}} \quad (6)$$

where S_c is the contact area.

Thus, the value of the thermal conductivity of the contact depends on the thermal conductivity coefficient of the materials of the contacting surfaces, contact medium thermophysical properties, quality of the processing of the contacting surfaces, contact area specific pressure.

For metal surfaces, the specific thermal conductivity of the contact is determined by the physical and mechanical properties of the materials, the purity of the processing of the contacting surfaces and the specific pressure.

Table 2 shows data on the specific thermal conductivity for the contacting pairs that are present in the terminal structure.

Table 2

contacting pairs material	$\sigma_{spec} \cdot 10^4, W/(m^2 \cdot K$
copper-aluminum	12,5
aluminum-aluminum	4,0
steel-aluminum	0,83
metal-paint-metal	0,05
steel-steel	1,5

To calculate the thermal conductivity of the contact, the value of the specific thermal conductivity must be multiplied by the contact area S_c.

$$\sigma_c = \sigma_{spec} \cdot S_c \quad (7)$$

At the 1st stage, convective heat transfer was simulated inside the monoblock housing to identify stagnant zones and calculate the convective heat transfer coefficient. The calculation results showed that the area of the ventilation holes in the plastic housing is sufficient for cooling the terminal, but their location relative to the heat sources does not allow heat to be efficiently removed outside the housing. The ventilation holes are mainly located in the rear part of the housing (Fig.3), and the heat sources are in the middle part under the matrix. A large number of connections of parts does not allow heat to be removed from the processor to the back of the case, thus, a stagnant high temperature zone is formed in the processor area. It should be noted that when choosing the parameters of ventilation grilles, in addition to considerations of cooling efficiency, it should also be guided by considerations of vibration resistance [6]

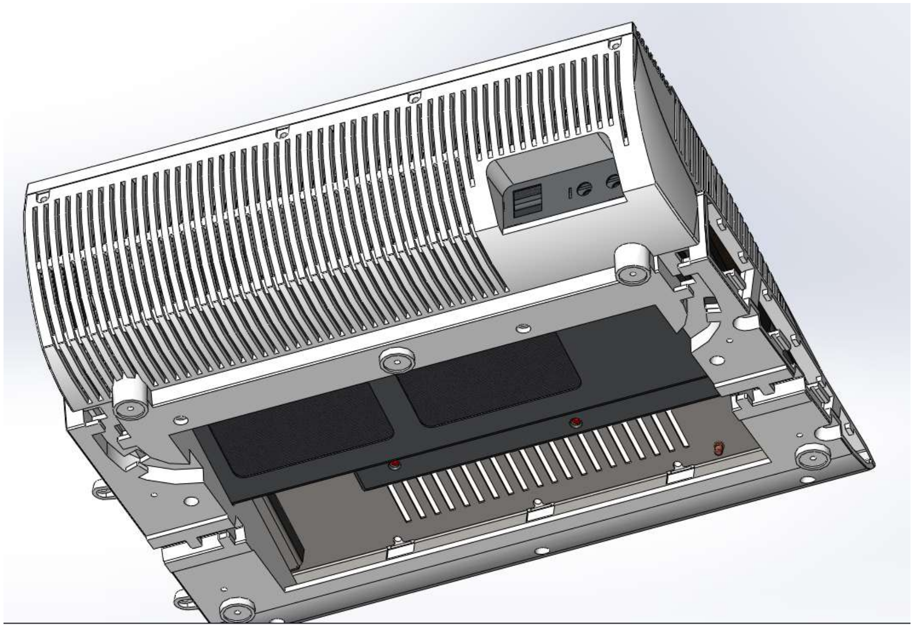

Fig. 3. Location of ventilation grilles in the rear part of the housing

At the 2nd stage, using the results of the calculation of convective heat transfer coefficients, the thermal conductivity of the parts involved in the cooling system of the terminal was simulated. The simulation results confirmed the temperature values obtained by measuring with a thermal imager. Figure 4 shows a temperature profile of the distribution of the most heat-stressed parts of the structure (the remaining details are hidden for clarity).

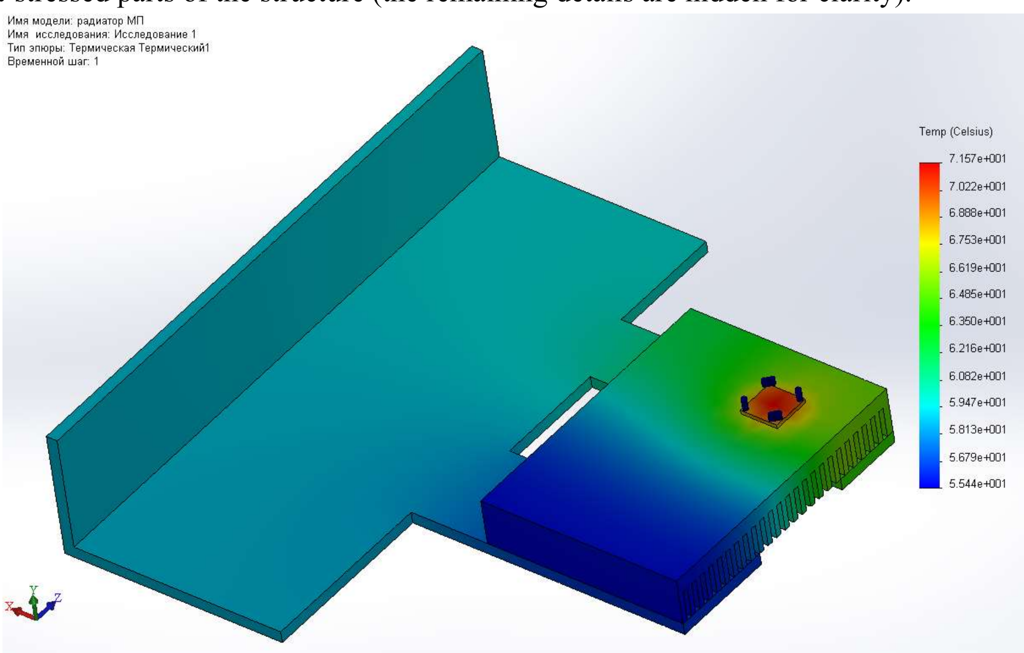

Fig. 4. Temperature distribution profile in the initial design of the heat sink

It can be seen from the figure that the temperature of the aluminum bracket mated with the radiator does not exceed 60°C, and the high temperature zone (65-70°C) concentrated in the immediate vicinity of the processor in an area that practically does not participate in convective heat exchange. This is due to the large amount of thermal resistance between the bracket and the radiator.

It is logical to assume that the essence of the changes that need to be made to the design consists in the distribution of the high temperature zone to the area of high convection, i.e. to the rear of the housing. The transfer of the motherboard to the rear of the case is impossible for design reasons, since sound reproduction devices are located in this area. The grilles in the rear of the terminal, in addition to cooling, also perform the function of sound transmission. For these reasons, the following design solutions have been proposed to improve heat distribution:

1. Standard aluminum radiator of the motherboard was excluded from the design and replaced with a copper heat-conducting element that transfers heat from the processor to the body parts. This reduced the number of thermal interfaces between the processor and the parts involved in the heat sink.
2. The 1 mm thick steel mounting plate used for mounting printed circuit boards has been replaced with a 6 mm thick aluminum plate. This made it possible to improve the heat transfer to the environment by increasing the area of the heat sink. In this design, the stove plays a major role in heat dissipation.
3. The pressure of the processor to the copper heat-conducting element is improved by installing additional springs.

Figure 5 shows a temperature distribution profile of the most heat-stressed parts of the modified structure.

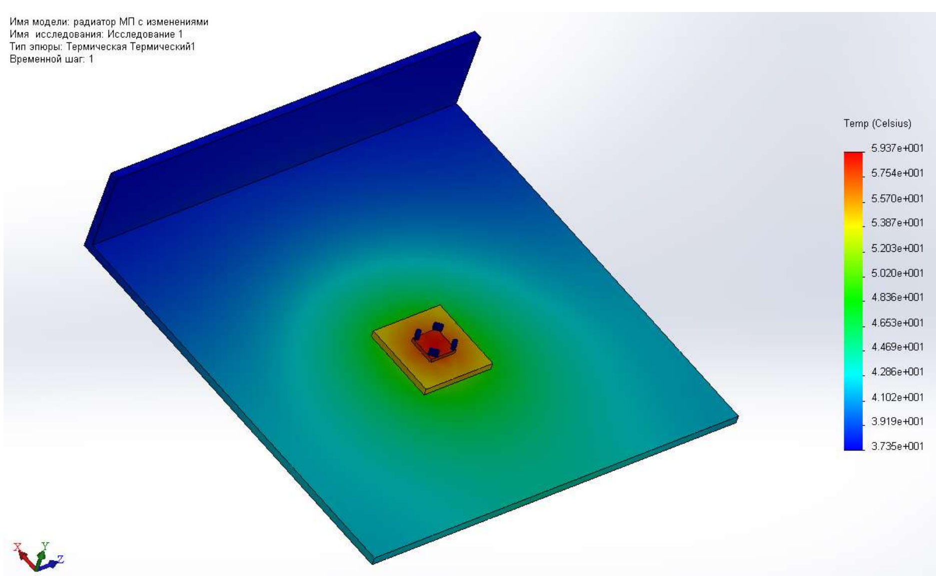

Fig. 5. Temperature distribution profile in the modified design of the heat sink

The temperature profile shows that the processor temperature has dropped to 60 °C, and the temperature distribution has become more uniform. This result was confirmed by measuring temperatures with a thermal imager and by monitoring the temperature of the processor with software.

An indirect result of the design changes has been a more uniform temperature distribution on the housing surface (Fig. 6).

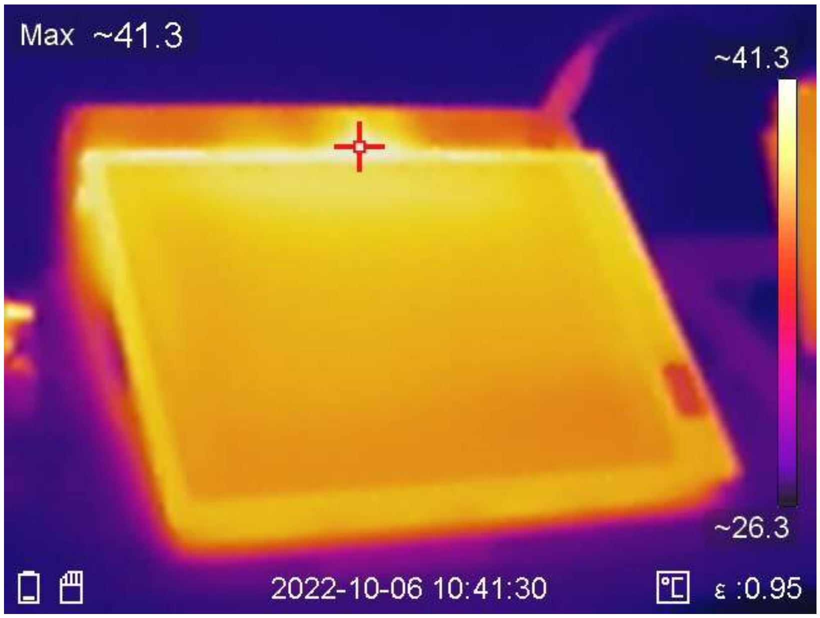

Fig. 6. Temperature distribution over the surface of the terminal housing

The decrease in processor temperature provided an increase in the motherboard's resource up to 10 years and an increase in processor performance by 15%.

The proposed method allows the provision of thermal calculation of all types of devices cooled by natural convection, taking into account the processes of thermal conductivity and convective heat exchange. The technique provides tools for predicting the impact of design changes on the temperature mode of operation of devices with passive cooling.

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