MATEC Web of Conferences **72**, 01086 (2016) DOI: 10.1051/matecconf/20167201086
HMTTSC-2016

SOLVING PROBLEM OF THERMAL CONDUCTION FOR PROVIDING STRENGTH OF ELECTRONIC UNITS ON THERMAL IMPACTS

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Abstract. Paper represents new approach to physical and mathematical modeling of thermal fields distribution in sealed electronic units on the base of introducing "effective parameters" of the system. Effectiveness of developed mathematical model and its computer implementing are demonstrated on the example of standard unit sealed by compound.

1 Introduction

Modern development of cutting-edge electronic components and units by applying new composite materials and aimed at providing reliability and resource is impossible without applying mathematical modeling of thermal and mechanical processes, which run inside these components during their operation.

Developing technologies for manufacturing sealed electronic systems demands considering impacts which are produced on their strength by as physical and mechanical so thermal factors.

2 Solution

The paper [1] represents physical and mathematical models, which were obtained and researched, for radial and tangential stress calculation in material of electronic component

$$\sigma_{r_1} = \frac{\mathrm{E}_1}{1-\mu_1}\left[-\frac{1}{r^2}\int_{R_1}^{r}\alpha_1\Delta t_1 r dr + \frac{r^2 - R_1^2}{r^2\left(R_2^2 - R_1^2\right)}\int_{R_1}^{R_2}\alpha_1\Delta t_1 r dr\right] + \frac{P_1R_1^2 - PR_2^2}{R_2^2 - R_1^2} - \frac{\left(P_1 - P\right)R_1^2R_2^2}{r^2\left(R_2^2 - R_1^2\right)}, \quad (1)$$

$$\sigma_{t_1} = \frac{\mathrm{E}_1}{1-\mu_1}\left[\frac{1}{r^2}\int_{R_1}^{r}\alpha_1\Delta t_1 r dr + \frac{r^2 - R_1^2}{r^2\left(R_2^2 - R_1^2\right)}\int_{R_1}^{R_2}\alpha_1\Delta t_1 r dr - \alpha_1\Delta t_1\right] + \frac{P_1R_1^2 - PR_2^2}{R_2^2 - R_1^2} + \frac{\left(P_1 - P\right)R_1^2R_2^2}{r^2\left(R_2^2 - R_1^2\right)}, \quad (2)$$

and in material of the selected compound cylinder

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$$\sigma_{r_2}=\frac{E_2}{1-\mu_2}\left[-\frac{1}{r^2}\int_{R_2}^{r}\alpha_2\Delta t_2 rdr+\frac{R^2-R_2^2}{r^2(R_3^2-R_2^2)}\int_{R_2}^{R_3}\alpha_2\Delta t_2 rdr\right]+\frac{PR_2^2-P_2R_3^2}{R_3^2-R_2^2}-\frac{(P-P_2)R_2^2R_3^2}{r^2(R_3^2-R_2^2)}, \quad (3)$$

$$\sigma_{t_2}=\frac{E_2}{1-\mu_2}\left[\frac{1}{r^2}\int_{R_2}^{r}\alpha_2\Delta t_2 rdr+\frac{R^2-R_2^2}{r^2\left(R_3^2-R_2^2\right)}\int_{R_2}^{R_3}\alpha_2\Delta t_2 rdr-\alpha_2\Delta t_2\right]+\frac{PR_2^2-P_2R_3^2}{R_3^2-R_2^2}+\frac{\left(P-P_1\right)R_2^2R_3^2}{r^2\left(R_3^2-R_2^2\right)}, \quad (4)$$

where μ_1,μ_2 – Poisson's ratios of component and compound materials correspondingly; E_1, E_2 – elasticity modulus of component and compound materials; α_1, α_2 – coefficient of linear expansion of component and compound materials; R_1, R_2 – internal and external radius of electronic component; R_2, R_3 – internal and external radius of compound; r – variable radiuses: $R_1 \le r \le R_2$, $R_2 \le R \le R_3$;

$\int_{R_1}^{r}\alpha_1\cdot\Delta t_1\cdot rdr$, $\int_{R_1}^{R_2}\alpha_1\cdot\Delta t_1\cdot rdr$, $\int_{R_2}^{r}\alpha_2\cdot\Delta t_2\cdot rdr$, $\int_{R_2}^{R_3}\alpha_2\cdot\Delta t_2\cdot rdr$ – temperature integrals; P – contact pressure:

$$P=\frac{2E_1E_2\left[\left(1+\mu_1\right)\left(R_3^2-R_2^2\right)\int_{R_1}^{R_2}\alpha_1\Delta t_1 rdr-\left(1+\mu_2\right)\left(R_2^2-R_1^2\right)\int_{R_2}^{R_3}\alpha_2\Delta t_2 rdr\right]}{E_2\left(R_3^2-R_2^2\right)\left[\left(1+\mu_1\right)R_1^2+\left(1-\mu_1\right)R_2^2\right]+E_1\left(R_2^2-R_1^2\right)\left[\left(1+\mu_2\right)R_3^2+\left(1-\mu_2\right)R_2^2\right]}, \quad (5)$$

Temperature drops Δt_1, Δt_2, present in formulas of thermal integrals (and stresses σ_{t_1}, σ_{t_2}) are defined as: $\Delta t_1 = t_{elcm}(r,\tau)-t_0$, $\Delta t_2 = t_{str}(r,\tau)-t_0$, where $t(r,\tau)$ – temperature of cylindrical surface of radius r in the moment of time τ, which is counted from the moment to transfer item from the constant temperature t_0 into the temperature t_1. For calculations t_0 is assumed to be the initial temperature of the body.

Using obtained formulas 1-5 for calculations required solving non-stationary problem of thermal conduction in compounded sealed unit, i.e. finding temperature distribution law over the volume of sealed unit from the moment as it is transferred from its highest temperature t_0 and to the lowest one t_1 (in our case from +70 deg C to -60 deg C) and until the whole volume receives the environmental (lowest) temperature. Solving this problem was offered by developing mathematical model for thermal fields calculation over the sealed unit volume on the base of introducing "effective parameters" [2], which consider inhomogeneity of the unit's material, since sealed unit has a complex structure and consists of many heterogeneous components: various electronic components and compound.

Effective parameters represent average physical and mechanical characteristics of all materials compiling the sealed unit. So temperature conductivity of the whole unit is defined as effective parameter by the formula:

$$\chi=\sum_{i=1}^{n}\upsilon_i\chi_i ,$$

where $\upsilon_i=\frac{V_i}{V}$, (i = 1,2, ..., n), V_i – volume, occupied by i-component in sealed unit (m^3), V – total volume of the sealed unit, χ_i – temperature conductivity of the i-component (m^{2}ph).

Using effective parameter χ allows assuming sealed unit as homogeneous body made from mixture of compound and electronic components materials.

Compounded sealed unit having box shape with coordinate origin in the cross point of its diagonals and axes along its principal axes of inertia and sizes $-a \le x \le a$, $-b \le y \le b$, $-c \le z \le c$ (fig. 1) has the following solution for the problem of thermal conduction:

$$t = (t_0 - t_1) \cdot \Phi_1\left(\frac{a-|x|}{2\sqrt{\chi \cdot \tau}}\right) \cdot \Phi_2\left(\frac{b-|y|}{2\sqrt{\chi \cdot \tau}}\right) \cdot \Phi_3\left(\frac{c-|z|}{2\sqrt{\chi \cdot \tau}}\right) + t_1 \qquad (6)$$

where t_0 – initial body temperature, t_1 – environmental temperature, Φ_1, Φ_2, Φ_3 – Laplace functions [3], τ – time.

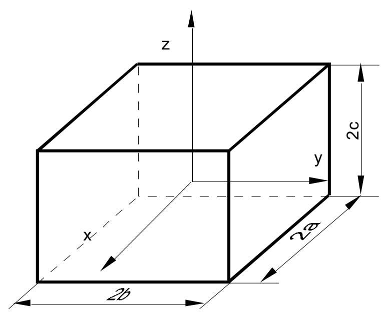


Fig. 1. Sealed unit represented as homogeneous rectangular box.

Obtained law of temperature distribution allows estimating temperature in any moment of time and in any point of the solid body. Moreover, this law makes possible to estimate the time of the complete cooling or heating a sealed unit.

The applied calculations of thermal fields in sealed units were to perform by using originally developed software on the base of MATHCAD. The developed software outputs on a display the two- and three-dimensional graphs of isotherms, which demonstrate thermal field in the selected section of a sealed unit in the specified moment of time, and also estimates time of complete cooling or heating sealed unit.

The thermal field for the sealed unit ZU 5.760.001 with sizes 21x14x8 mm was calculated for the thermal impact in temperature diapason from t_0 = +70 deg C до t_1 = -60 deg C.

The calculation was conducted at partial volume of compound (type TSK-25) V_1=1576 mm^3 and volume of electronic components equal V_2=776 mm^3. Physical and mechanical characteristics of resistor's and compound's materials are: temperature conductivity χ_1 = 0.18 mm^2/s, χ_2 = 0.414 mm^2/s; thermal conductivity $К_1$ = 0.837 W/(m·deg), $К_2$ = 0.33 W/(m·deg); thermal capacity C_1 = 0.253 W·h/kg·deg, C_2 = 0.395 W·h/kg·deg; density ρ_1 = 2000 kg/m^3, ρ_2 = 1600 kg/m^3.

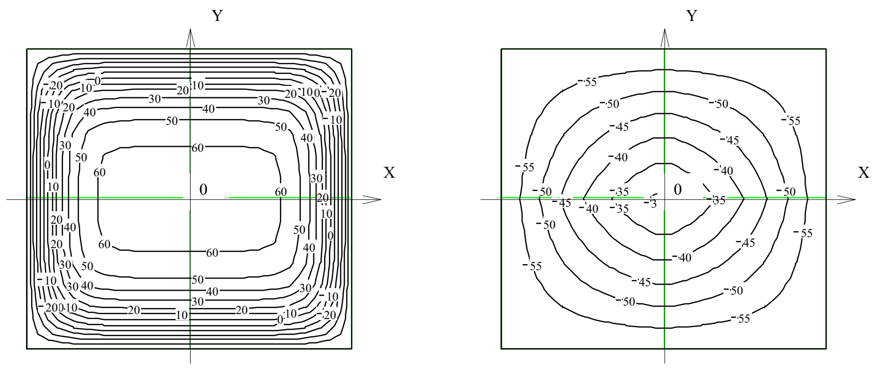
Fig. 2 shows temperature distribution in horizontal section by the plane z = 0 (fig. 1). Isotherms are built in various moments of time up to the complete cooling.

The temperature calculation conducted in the set time interval resulted that actual cooling a sealed unit occurs in 1366 sec (22.7 min).

For experimental estimation of the complete cooling time the sealed unit ZU5.760.001 had been prepared by attaching microthermocouple XK_{68} before it was sealed by compound ESK-25. After compound had polymerized the unit was subjected to the range of thermal impacts (thermal cycling) in the temperature range from +70 deg C to -60 deg C. Indications of microthermocouple were recorded on the tape of light-beam oscillograph

H071.4M. As result of conducting 10 thermal cycles the average time of cooling sealed unit – 1160 seconds (19.33 min) has been measured, which deviation from estimated one is negligible. Noteworthy is that in manufacturing process when such units are subjected to technological testing, which is conducted in order to improve reliability of the product, the cooling (heating) time makes 1 hour: product is first placed in a heat chamber; then it is transferred to a cooling chamber (the transfer time is limited to few seconds); exposure period in chambers lasts until the thermal balance (1 hour). The total amount of thermal cycles equals three. Such testing is supposed to detect hidden design defects and reject potentially unreliable products.

Thus, modeling and estimating thermal field in sealed units and its time rate allows optimizing technological time for conducting thermal impacts in the process of their manufacturing. So for the case given above the exposure time for thermal impacts in temperature range from +70 deg C to -60 deg C is recommended to optimize and shorten down to 23-24 min as longest.



a) b)

Fig. 2. Isotherms for horizontal section of the sealed unit in time moments τ=8s (a), τ=200s (b).

After the problem of thermal conduction has been solved for thermal impacts in the volume of the whole sealed unit whose material was considered as a composite one and the shape of its individual components was not considered at all the further research of temperature distribution near the estimated electronic component and surrounding layer of compound appears to be reasonable. Therefore the problem of non-stationary radial distribution of temperature in electronic component and compound has been posed and solved; these results will be represented in the further papers.

3 Conclusion

The paper represents mathematical models for thermal fields calculation over the volume of the sealed unit on the base of introducing "effective parameters" which represent average physical and mechanical characteristics of all materials compiling the sealed unit. The developed model allows estimating thermal field distribution in time and over the volume of the solid body and also optimizing technological time for conducting thermal impacts in the process of manufacturing sealed units.

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