American Association for Science and Technology
AASCIT Communications
Volume 1, Issue 2
August 20, 2014 online

American Association for Science and Technology

Experience Formulating and Solving Inverse Problems for Strength Design of Electronic Equipment

Goroshko A.

Keywords: Inverse Problem, Identification Strength, Compound, Electronic Element

The paper shows the results of formulation and solution of inverse problems for strength compounded elements electronics. Considered and studied real construction - micro-module. A parameter identification of a mathematical model, as close to the real conditions of the structure is offered. Decomposition of a mixture of probability distributions experimentally obtained values of destructive forces in the tests carried out. The tolerances of valid values of the mathematical model by solving the optimization problem are calculated. For the case where the physical and mechanical characteristics of the elements do not correspond to those found with the limits of tolerances and do not provide the structural strength, proposed some solutions to this problem. In this way, there is a selective assembly.

Introduction

Sealing of electronic equipment (EE) elements is widely used to improve the reliability of their operation in terms of temperature, pressure, moisture, etc. [1,2]. In particular, sealed micromodules (MMs) are used in control equipment in aircraft and rocket industries.

During the operation of MMs the structure "electronic element-compound" is subject to dangerous stresses caused by the difference of the coefficients of linear thermal expansion, Poisson's ratio and elastic moduli of these materials, which leads to the destruction of MMs and consequent destruction of the expensive complex systems they belong to.

In order to eliminate such defects in resistor-compound structure, it is necessary to provide the strength of the materials of resistor and sealant. In order to do this, one has to determine the primary factors that influence the magnitude of the stresses in the materials of resistor and sealant, and find the range of their values (tolerance) which ensure that the conditions of strength for each of the components of the mentioned structure are met.

$$\sigma_{\max i} \le [\sigma_i],\ i \in \mathbb{N}\,.$$

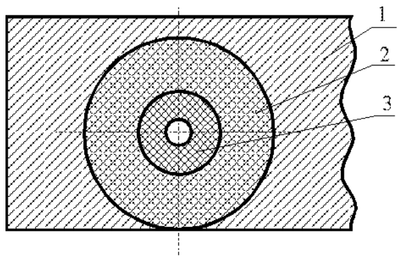

Fig. 1. Cross-section of an electronic element, compound polymerized with compound:

1 - compound,
2 – isolated compound cylinder,
3 - electronic element.

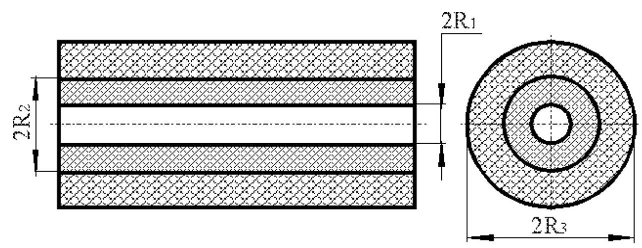

Fig. 2. The electronic element surrounded by a layer of compound

In [3] analyzed the causes of MM and the mathematical model of stress in the system of electronic element, compound. The model proved to be suitable for the calculation of the strength of parts of the system, but the analysis showed that variations in the physical and mechanical properties of compounds in the production of MMs can reach 300% and depends on many factors, such as the place where compound components are manufactured. Therefore, it was necessary to find the exact values of these characteristics for particular party material. In addition, the characteristics of compounds in the temperature range of -60°C…20°C are unknown, although the MMs are operated in such temperatures.

The result was posed and solved the inverse problem of identifying physical and mechanical properties of polymer compounds for further use in a mathematical model describing the magnitude of the contact pressure of ceramic-compound.

Solution of the Problem of Identification

The study [4] is focused on the causes of MMs destruction and provides a mathematical model of stress calculation in the system "electronic element-compound", represented by figures 1 and 2.

The formula for calculating contact pressure in the materials of resistor and compound at a stable temperature looks the following way (1).

$$PB\chi_2 - P\chi_1 + \alpha_2 t = -(E + CD)P + \alpha_1 t \quad (1)$$

where α_1, α_2 - is the coefficient of linear thermal expansion in the material of the product and compound, respectively; E_1, E_2 - their elastic moduli; μ_1, μ_2 - their Poisson's ratio, $B = R_3^2/(R_3^2 - R_2^2)$, $C = (2-\mu_1)/E_1$, $D = R_1^2/(R_2^2 - R_1^2)$, $E = (1-2\mu_2)/E_1$, $\chi_1 = (1-2\mu_2)/E_2$, $\chi_2 = (2-\mu_2)/E_2$.

For their determination it is necessary to write a system of three linear algebraic equations.

$$P_i B_i \chi_2 - P_i \chi_1 + \alpha_2 t = -(E_i - C_i D_i)P_i + \alpha_{1i} t, \quad i = 1,2,\ldots,3, \quad (2)$$

where the indices of coefficients B_i, C_i, D_i, E_i and contact pressure P_i correspond to the vector of parameters $\bar{x}_i = \{\alpha_{1i}, \mu_{1i}, E_{1i}, R_{1i}, R_{2i}, R_{3i}\}$ of the "i" trial sample (i =1,2,…,3).

The authors developed an experimental method of calculation with testing parameters which can simultaneously identify the coefficient of linear thermal expansion, elastic modulus and Poisson's ratio of a compound [4].

The idea of the method is that the studied material is connected with other trial materials, the properties of which are well known and differ from the properties of the material. Whereas the connecting parts should have specific forms that make it possible to describe the stress-strain state of the samples in real structures with the same equations.

In order to determine the physical and mechanical characteristics it is offered to consider the values of the identified parameters to be unknown in the calculation model. It is suggested that the values of the parameters of trial structures, which can be measured accurately by experimental means in the process of product operation, and characteristics of trial materials and geometric dimensions should be inserted in the same model as input information. Producing a number of test samples with values of physical and mechanical properties that are set so that the measured deformation values would be different, it is possible to write the number of linearly independent equations with the identified parameters based on the computation model which is required for their determination.

To identify the above physical and mechanical characteristics compound that surrounds and seals the resistor was made double-layer cylindrical design "trial material - compound", choosing as test material, the characteristics of which are well known and are different from the similar characteristics of compound. In these structures at the interface of materials at extremes of temperature occurs contact pressure. The parameters that are included in the selected mathematical model and can be accurately measured experimental methods are emerging under the influence of contact pressure strain on the outer surface of the cylinder test, the value of which is related to the values of the stress Hooke's law. Value Hooke's law, and the value specified by the author for the developed models allow for known radial size structures of defined strain values experimentally found value of contact pressure.

The value of the proposed method of identification is that it makes it possible to accurately determine the physical and mechanical properties for a particular batch of material, temperature, and especially the design model that describes the stress-strain state of an electronic element - the compound. This is due to the fact that any mathematical model of the real product contains all sorts of assumptions and substituting it with inaccurate coefficients can compromise even the most accurate calculation scheme. And using the method of identification, we developed a mathematical model is effective because it will be substituted identifiable characteristics derived from the same mathematical model.

Identifiable physical and mechanical characteristics of compound EZK-25 entered the developed mathematical model as it is specified parameters (table 1).

Table 1. *The value of physical and mechanical properties of resistor ceramic*

Temperature range	Young's modulus E, N/mm^2·10^4	Poisson's ratio μ	Local thermodynamic equilibrium α, 1/degree ·10^{-6}
-20°C…-30°C	13,794	0,294	7,0023
-30°C…-40°C	13,658	0,282	6,376
-50°C…-60°C	12,95	0,276	5,898

With this method was calculated vector of nominal values of primary factors model $\mathbf{x}_0 = \{\alpha_{10}, \alpha_{20}, \mu_{10}, \mu_{20}, E_{10}, E_{20}, R_{10}, R_{20}, R_{30}\}$.

Next, it was necessary to determine regulated reasonable values of output characteristics of the model. For this purpose, the allowable stress in the studied materials installed by measuring forces that destroy the base ceramic resistors and custom designs are made of epoxy, with stretching (squeezing) loads.

Given the fact that the law of distribution experimentally obtained values destructive efforts ceramic resistors was polymodal, and was placed second inverse problem is solved - problem decomposition, ie the splitting mixture of probability distributions, because the structure of the data is unknown. This is the problem of determining the quantity and fate parameters of each sub-samples for the total sample.

Solution of the Problem of Decomposition of a Mixture of Probability Distributions

According to the proposed method of handling the distribution blends, the two modal histogram was approximated by a linear combination of Gaussians with weights ρ_i of the available

$$f(x,\mu_i,\sigma_i,\rho_i)=(2\pi)^{-\frac{1}{2}}\sum_{i=1}^{N}\rho_i\sigma_i^{-1}\exp\left[-(x-\mu_i)^2\left(2\sigma_i^2\right)^{-1}\right],\ N=2, \quad (3)$$

where μ_i and σ_i - the expected value and standard deviation i -th subsample, each of which is influenced by its dominant reasons, ρ_i - probability of falling into the in i -th sub-sample, $\sum_{i=1}^{N}\rho_i=1$, $0\le\rho_i\le1$, x - random variable, in this case the measurement result destroying efforts ceramic resistor.

Using the method splitting mixtures of probability distributions revealed that two modal combustible mixture distribution is described by a PDF of type (3) with parameters ρ_1 =0,66, μ_1 =74, σ_1 =6,6; ρ_2 =0,34, μ_2 =114, σ_2 =5,7, schedule is presented in Fig. 3.

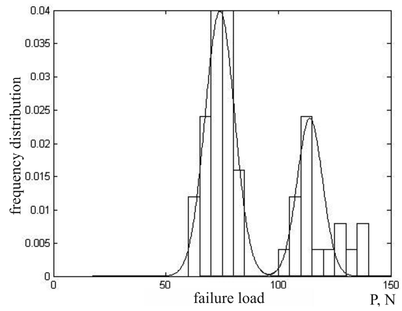

Fig. 3. *Distribution of destructive efforts in ceramic resistors OMLT-0,125 and schedule of the desired distribution density mixture*

In the same way the values of strains that destroy ceramics in compression and the related compound properties have been obtained and the values of boundary stresses in the material have been calculated (Table 2).

For further processing statistical data obtained subsamples considered less durable resistors, then maybe go into error margin entire sample. Using the obtained data was determined allowable stress values grounded in the ceramics and compounds.

Next, it was necessary to answer the question: to what extent must be on the physical and mechanical properties and geometrical dimensions of the model parameters in order to provide guaranteed structural strength resistor-compound?

Table 2. *Limit strains in the studied materials*

Type resistor or compound	Limit stresses $\sigma_в$, MPa	
	Tensile	Compressive
Resistor OMLT-0,125	68,72	500
Compound EZK-25	108,00	110

So was posed and solved by a third inverse problem - the problem of optimization of tolerances on values of physical and mechanical characteristics of materials and geometric design size resistor-compound.

Optimization of Admissible Values of the Model Parameters

Taking into account technical specifications, the primary limiting factors in the model as a system of inequalities can be written:

$4\cdot10\text{-}6\le\alpha_1\le8\cdot10\text{-}6$, degree-1; $\quad 0{,}25\le\mu_1\le0{,}35$; $\quad 1{,}0\cdot105\le E_1\le1{,}5\cdot105$; MPa

$35\cdot10\text{-}6\le\alpha_2\le45\cdot10\text{-}6$; degree-1 $\quad 0{,}31\le\mu_2\le0{,}35$; $\quad 0{,}5\cdot104\le E_2\le1{,}5\cdot104$; MPa (4)

$1{,}9\cdot10^{-4}\le R_1\le2{,}1\cdot10^{-4}$; m $\quad 7{,}4\cdot10^{-4}\le R_2\le7{,}6\cdot10^{-4}$; m $\quad 1{,}1\cdot10^{-3}\le R_3\le2{,}0\cdot10^{-3}$, m.

Generally based task assignment tolerances on physical and mechanical properties of materials and compound resistor and the geometric dimensions of the study design can be formulated as follows. For a given nominal values of the primary factors determine such tolerances δ_i, i =1,2,…9 from the nominal values, so that the resulting parallelepiped fulfilled the conditions (5).

$$x_{i0}-\delta_i/2\le x_{i0}\le x_{i0}+\delta_i/2,\ i=1,2,\ldots,9. \quad (5)$$

To select a particular parallelepiped it is necessary to impose an additional condition, which is why it is offered to introduce an optimality criterion or economic or industrial, or any other substance. Setting an optimality criterion allows to reduce the problem of determining the tolerances to the problem of optimizing the chosen objective function under constraints (5).

Since for reasons of economy it is desirable to maximize the tolerances on all parameters, the considered optimization problem is multi-objective (vector), and a set of optimal values of tolerances can be found by minimizing such objective functions as

$$F_i=-\delta_i\to\min,\ i=1,2,\ldots,9. \quad (6)$$

To reduce this problem to a multi-criteria one-criterion (scalarization) [5], which is why the linear convolution of criteria form $\tilde{F}_1=\sum_{i=1}^{9}c_i\delta_i\to\max$ were used, where $c_i\ge0,\ \sum_{i=1}^{9}c_i=1$ - normalized positive number, defined with industrial or economic reasons. Thus, the problem is reduced to determining values of δ_i i=1,2,…,9, at which the maximum of one of the objective functions $\tilde{F}_1$

subject to the constraints (4) with a difference of temperature between +70°C to -60°C is reached.

In the work [6] it is shown that different methods of convolution of criteria can lead to different results, which are very different, indicating that the importance of the step of forming a global criterion for solving multiobjective problems.

The paper proposes to determine the significance of the ranks of private criteria based on their pairwise comparison, and used fuzzy logic and a comparison with a scale linguistic evaluations. Grades criteria c_i based on the matrix of pairwise comparisons were determined by the approximate method proposed by T. Saaty [7]. According to this method, the approximate values of the vector of ranks are as geometric mean values of each row of the matrix of pairwise comparisons, normalized by dividing by the sum of the geometric.

Thus, for the construction of the resistor type OMLT-0,125, sealed compound EZK-25, was held definition of tolerances on physical and mechanical properties of materials and compound resistor and the geometric dimensions of the design, which ensures the strength of structural elements (Table 3).

When solving inverse problems above were applied developed in [8], statistical methods and algorithms to ensure stability and improve the accuracy of solutions of inverse problems.

Conclusions

Experience the formulation and solution of inverse problems of parameter identification, decomposition of a mixture of probability distributions experimentally obtained values of acceptable values of parameters of optimization mathematical models has shown its effectiveness and high accuracy in solving problems of strength compounded elements CEA.

Meanwhile, the question arises - what to do with ceramic resistors, physical and mechanical properties which are not included within the set tolerances? A promising direction issued two directions for further research:

The development of computational methods to perform selective compilation of MM in which the parties to compound with the values of physical and mechanical characteristics that go beyond the limits (4), were selected resistors with ceramic features that ensure structural strength;

The conditions of impossibility of performance (1), proposed compiling MM with different allowable stresses for subsequent use in designs with less (more) listed in the technical mechanical loads.

These studies are beyond the scope of this paper and will be published in subsequent papers.■

Table 3. *The boundary of the set of values of the primary factors*

The criterion of optimality $\tilde{F}_1 = \sum_{i=1}^{q} c_i \delta_i \to \max$; $c_1 = c_2$ =0,17; $c_3 = c_4$ =0,04; $c_5 = c_6$ =0,08; $c_7 = c_8 = c_9$ =0,14		
The primary factors	Limit values set	
	Lower	Upper
$\alpha_{10} \cdot 10^{-6}$, degree^{-1}	5,5	6,5
$\alpha_{20} \cdot 10^{-6}$, degree^{-1}	38	42
μ_{10}	0,290	0,294
μ_{20}	0,315	0,345
$E_{10} \cdot 10^{5}$, MPa	1,22	1,40
$E_{20} \cdot 10^{5}$, MPa	0,098	0,102
$R_{10} \cdot 10^{-3}$, m	0,190	0,210
$R_{20} \cdot 10^{-3}$, m	0,740	0,760
$R_{30} \cdot 10^{-3}$, m	1,100	2,000

Goroshko A.
Khmelnytskyi National University, Mechanical Engineering Faculty, Khmelnytskyi, Ukraine
royzman_V@mail.ru

References

[1] Morozov D.I, Andreev P.G., Naumova Y.U. Protecting electronic equipment from the effects of climatic factors // BBK 32ya43 P 45. - 2011. - P. 255.

[2] Masuko, Shingo. "Method of packaging electronic parts." U.S. Patent No. 7,200,924. 10 Apr. 2007.

[3] A. Lokoschenko, S. Petrashchuk, V. Royzman. Evaluating and ensuring the strength of the system "electronic element - the compound." Journal of Khmelnitsky National University, № 5 '2012. P. 193-197

[4] A. V. Goroshko. Identification of physical and mechanical properties of compound by solving inverse problems / A.V. Goroshko, V.P. Royzman, A. Bubulis // Vibroengineering Procedia of International Conference "Vibroengineering – 2013",17-19 September 2013, Druskininkai, Lithuania. P. 81-86

[5] A. Goroshko. Representation and processing of statistical data that do not conform to the laws of a unimodal distribution / A.V. Goroshko, V.P. Royzman // Mechanical Engineering and Engineering Education. -2013. Number 3. P 56-77

[6] Zitzler E. Evolutionary algorithms for multiobjective optimization: Methods and applications. - Ithaca: Shaker, 1999. - P. 63.

[7] Saaty T. L. A scaling method for priorities in hierarchical structures //Journal of mathematical psychology. – 1977. – T. 15. – №. 3. – C. 234-281.

[8] V. Royzman, A. Goroshko. Multiple inverse problem. - Journal of Vibroengineering. September 2012. Volume 14, ISSUE 3. ISSN 1392-8716. C 1417-1424