Devices and Systems Design Reliability Estimation

Leonid Nedostup, Yuriy Bobalo, Myroslav Kiselychnyk, Oxana Lazko

Abstract – **The updated approach for devices and systems reliability estimation was proposed. An two-dimensional " Stress–strength " probability model based on application of Gram-Charlier and Edgeworth rows was obtained.**

Keywords – **design reliability, stress-strength models, Gram-Charlier rows.**

I. INTRODUCTION

An important component of electronic devices and systems reliability is reliability of their construction. Complicating structures and simultaneous aspiration to minimize the mass and dimensions leads to a decrease in structure's durability reserve. At the same time requirements for reliability of construction should not be exceeded because they can lead to unnecessary use of resources and reduction of other indices of products quality. The feature of this type of techniques structures is wide range of materials and semi-finished products application, including metals, alloys, ceramics, ferrites, plastics, etc., which are characterized by different strength and vibration immunity, as well as sensitivity to destabilizing factors such as temperature changes, the influence of magnetic and electromagnetic fields, radiation, chemical influences. A large number of connections made by electric, laser, thermal-compressing, ultrasonic welding, gluing and soldering are present in constructions. They provide not only mechanical strength design but and other nonmechanical parameters as well such as the desired electrical conductivity, magnetic permeability, vacuum density, corrosion resistance, etc. The deterioration of parameters of construction elements can cause sensitivity and apparatus precision reduction , increased energy use, control loss and other phenomena that cause partial or complete efficiency leakage. These factors in their physical and mathematical nature are multidimensional and stochastic, and their parameters change in time for the most part represent the unsteady and preferably not ergodic processes. Today, different approaches and methods for estimating the reliability of devices and systems construction are using . Typical for them is that they in their majority are based on the determination of the correlation of achieved performance properties of products with a complex influence on them by set of destabilizing factors due to their purpose and the specific operating conditions.

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II. MAIN PART

The process of apparatus failure can occur in two main schemes: structures instant destruction or gradual drift of parameters, which also leads to failure. Also it is possible a combined option. In each of them, apparatus loses its efficiency when influence of set of destabilizing factors forms the stress S, which exceeds its destructive level of R. This level is traditionally defined as a level of carrying ability of construction elements in general. With regard to electronic devices and systems, the term "stress" and "strength" have a wide meaning, which is not limited to "mechanical" semantics. To these constructions the stress can not only be static or dynamic, but caused by the action of vibration, acoustic, hydraulic, windy, radiation, thermal and other stress forms. These stresses can be mutually-correlated and characterized by different influences.

According to general principles of evaluation of complex objects quality, which include the constructions of radio-electronic devices and systems, the S and R values are considered as stress and strength vectors

$$S=[s_1, s_2, \ldots, s_n]^T \tag{1}$$

$$R=[r_1, r_2, \ldots, r_n]^T \tag{2}$$

The physical content of the components s_1, s_2, ..., s_n and r_1, r_2, ... r_n determined by partial stress and strength capacity and by the set of destabilizing factors.

The area of efficiency saving is characterized by condition S<R, and the area of disability - $S \geq R$. Since the vectors S and R and their components are functions of time, the probability of construction failure Q (t) is determined by the equations:

$$Q(t)=Q\{[\, S(t)-R(t)]\geq 0\} \tag{3}$$

or

$$Q(t)=Q\{[\, S(t),R(t)]\in D\} \tag{4}$$

D - area of intersection between distributions of values S and R.

Thus the probability of failure Q (t) in general case depends on the stress and strength values, and also on parameters of their distributions.

For two-dimensional " Stress–strength " model probability Q (t) is determined by the equation:

$$Q(t) = \iint\limits_D f[s(t), r(t)]ds(t)dr(t) \tag{5}$$

f [s (t), r (t)] - two-dimensional density of stress-strength parameters probability distribution .

In case when stress and strength are independent

$$f[s(t),r(t)] = fs(t) \cdot fr(t) \quad (6)$$

Then

$$Q(t) = \int_{0}^{\infty} fr(t) \left[\int_{r=s}^{\infty} fs(t) ds(t) \right] dr(t) \quad (7)$$

In this formula integration area D is given by conditions:

$$0 \le r < \infty \quad (8)$$

$$r \le s < \infty \quad (9)$$

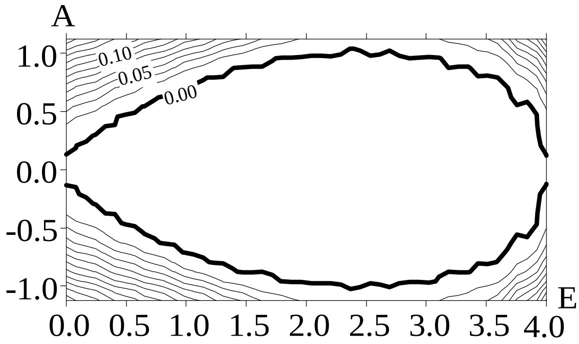
In many famous works, dedicated to the problem of estimating the reliability of construction of radio-electronic devices and systems, the normal law is taken as model of distribution of s and r values. The normal law application is justified in the case where the process of forming stress and strength characterized by the cumulative effect of a large number of independent random factors with different distribution laws without overflowing. With the known functions of mathematical expectations $m_r(t)$, $m_s(t)$ and mean square deviation $\sigma_r(t)$, $\sigma_s(t)$ the probability of construction failure is determined by Q(t) dependence:

$$Q(t) = \frac{1}{2} - \Phi\left[\frac{m_r(t) - m_s(t)}{m_s(t)\sqrt{\left(\frac{\sigma_r(t)}{m_s(t)}\right)^2 + \left(\frac{\sigma_s(t)}{m_s(t)}\right)^2}} \right] \quad (10)$$

Due condition of normality and stationarity of stress changing processes during operation period refuse probability Q (t) can be determined by methods based on the theory of emission.

Numerous studies of processes of manufacture and operation of apparatus show that often without sufficient grounds the normal distribution law of these parameters becomes a convenient idealization of real statistical regularities. Plurals of real influences in forming the distribution during life cycle cause them to deviate from the normal law, manifested in their asymmetry and sharpness. Ignoring them is not always justified [1].

It should be noted that probabilities of stress characteristics which are needed for the calculation of construction reliability can be determined only experimentally by statistical methods. In cases when the skewness parameters A of resulting distributions are within [-1,0 <A ≤ 1,0], and kurtosis parameters E within [0 <E ≤ 4,0] convenient distribution models of s and r values can be rows of Gram-Charlier and Edgeworth [2].



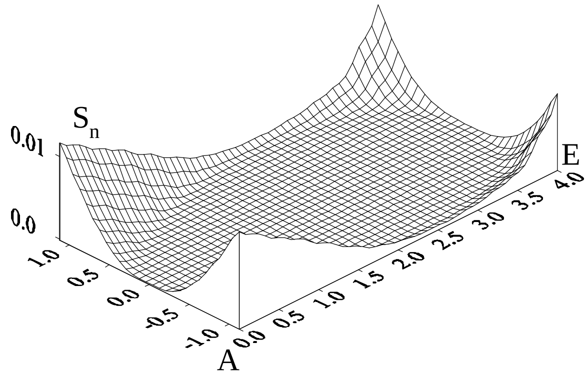


Fig.1. Three-dimensional representations of the dependence of the negative area under the curve on the values of skewness A and kurtosis E coefficients

The number of members of these rows is chosen with consideration of acceptable approximation error, associated with irregularity [3].

III. Conclusion

In the paper the most actual approach for devices and systems reliability estimation was proposed. The case of independent stress and strength was described. It was shown that in cases when the skewness parameters A of resulting distributions are within [-1,0 <A ≤ 1,0], and kurtosis parameters E within [0 <E ≤ 4,0] convenient distribution models of s and r values can be rows of Gram-Charlier and Edgeworth.

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