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Lytvynenko Volodymyr, Candidate of Technical Sciences, Associate Professor, Department of Radio communication, Radio broadcasting and television

Литвиненко В.А., кандидат технічних наук, доцент, кафедра апаратура радіозв'язку, радіомовлення і телебачення
ORCID ID: 0000-0003-4950-5168
e-mail: litvvladimir35@gmail.com

Syanov Olexandr, Doctor of Technical Sciences, Professor, Department of Radio communication, Radio broadcasting and television

С'янов О.М., доктор технічних наук, професор, кафедра апаратура радіозв'язку, радіомовлення і телебачення
ORCID ID: 0000-0003-4120-4926
e-mail: alexandr.sianov@gmail.com

Ryazancev Oleg, Candidate of Physical and Mathematics Sciences, Associate Professor, Department of Radio communication, Radio broadcasting and television

Рязанцев О.В., кандидат фізико-математичних наук, доцент, кафедра апаратура радіозв'язку, радіомовлення і телебачення
ORCID ID: 0000-0002-7253-5966
e-mail: ryzancevtr@gmail.com

Huliesha Olena, Candidate of Pedagogical Sciences., Associate Professor, Department of electronic

Гуляша О.М., кандидат педагогічних наук, доцент, кафедра електроніки
ORCID ID: 0000-0002-7512-5671
e-mail: gulesha@gmail.com

Ulanova Vitalia, student of the Department of Radio communication, Radio broadcasting and television

Уланова В.Є., студент, кафедра апаратура радіозв'язку, радіомовлення і телебачення
e-mail: vitaliaulanova@gmail.com

Dniprovsky State Technical University, Kamianske
Дніпровський державний технічний університет, Кам'янське

COMPUTER SYSTEMS OF MATHEMATICAL CALCULATIONS FOR THE ANALYSIS OF METROLOGICAL RELIABILITY OF RADIO MEASUREMENT INSTRUMENTS

КОМП'ЮТЕРНІ СИСТЕМИ МАТЕМАТИЧНИХ РОЗРАХУНКІВ ДЛЯ АНАЛІЗУ МЕТРОЛОГІЧНОЇ НАДІЙНОСТІ ЗАСОБІВ ВИМІРЮВАНЬ

Considers the possibility of using MathCAD and MATLAB computer systems for mathematical calculations in the study of mathematical methods of the theory of reliability of measuring instruments(MI), when it is necessary to perform a large number of mathematical operations and calculations of various levels of complexity. Therefore, in order to obtain the specified results, an algorithm for the analysis of the reliability of the system was proposed when using MathCAD.

In the process of performing the calculations of the reliability functions of the MI, the possibilities of the MathCAD and MATLAB systems to calculate the time integrals of the fault-free operation of the MI in several ways, and to display the initial information graphically, were studied. The solution to the problem of researching the reliability functions of the MI from the parameters of the metro-

logical service system and with statistical and probabilistic-physical models of metrological failures in the considered systems was found in a quick and simple way, which allowed to reduce the time spent on calculations.

Keywords: *algorithmic language, MathCAD and Mat lab software tools, reliability, radio measurement tools.*

У статті викладаються теоретичні основи надійності радіотехнічних пристроїв і її взаємодія з комп'ютерними обчисленнями. Розв'язок задач по теорії надійності засобів радіовимірювань проведений за допомогою математичного пакету програм MathCAD та MATLAB.

Розглядається можливість застосування комп'ютерних систем математичних розрахунків MathCAD і MATLAB при вивченні математичних методів теорії надійності засобів вимірювань, коли необхідно виконувати велике число математичних операцій і обчислень різного рівня складності. Тому для отримання визначених результатів був запропонований алгоритм аналізу надійності ЗВ при використанні MathCAD.

Розглянуті обчислювальні методи інтегрування дискретно-безперервних функцій метрологічної надійності. Приведено рекурсивні функції математичної теорії надійності і методи інтегрування даних функцій. Показано практичне застосування систем MathCAD і MATLAB при вивченні методів математичної теорії надійності радіовимірювальної апаратури. За допомогою прикладів теорії метрологічної надійності ЗВ продемонструвати комплексне застосування програм MathCAD і MATLAB для інженерів та наукових співробітників в області математичних методів теорії надійності.

У процесі виконання розрахунків функцій надійності ЗВ вивчені можливості систем MathCAD і MATLAB обчислювати інтеграли часу безвідмовної роботи ЗВ декількома способами, відображати вихідну інформацію графічним способом. Розв'язок задачі дослідження функції надійності ЗВ від параметрів системи метрологічного обслуговування та при статистичних і ймовірно-фізичних моделях метрологічних відмов в розглянутих системах був знайдений швидким і простим способом, що дозволило знизити часові затрати на проведення обчислень.

Ключові слова: *алгоритмічна мова, програмні засоби MathCAD та MATLAB, надійність, засоби радіовимірювань.*

Problem's formulation

About universal "MathCAD" and "MATLAB" program packages. At the end of the 20th century, with the appearance of new software, such as: MathCAD, Eureka, Maple, Mathematica, MATLAB, etc. integrated mathematical software systems began to enjoy great popularity among scientists. Being in great demand since the beginning of their existence, they received huge support among users, thanks to the familiar interface and ease of use. The development in this area suggests that interest in them does not fade, even at the moment of their existence.

Analysis of recent research and publications

MathCAD is one of the widely used programming systems. Belongs to the class of automated design systems. It is mainly used for mathematical calculations. MathCAD was originally created for the numerical solution of mathematical problems, it is focused on solving the problems of applied rather than theoretical mathematics. MathCAD includes many operators, built-in functions and algorithms for solving mathematical problems that are directly applicable to the issues considered by the theory of metrological reliability. The MathCAD package makes radical changes in the study of many technical disciplines, including radio measurements. When using analytical methods, solving the problem of analyzing the discrete-continuous functions of the metrological reliability of radio measuring equipment is extremely time-consuming, since a logarithmic scale is used for large ranges of failures and the period of verification work. With the use of MathCAD, this problem belongs to the number of ordinary ones and is solved [1—4].

The MATLAB (Matrix Laboratory) language is a high-level interpreted programming language that includes matrix-based data structures, a wide range of functions, an integrated development environment, object-oriented capabilities, and interfaces to programs written in other programming

languages. MATLAB tools are designed for collaborative work and integrate with parallel computing environments, graphics processors, and C code generation [5—6].

Names of functions and captions are familiar and memorable. The desktop environment is configured for iterative design and scientific research. The documentation is written for engineers and scientists, not for programmers. Modern MATLAB is a highly effective language of engineering and scientific calculations, which has incorporated advanced experience in the development and computer implementation of numerous methods [6—9].

Formulation of the study purpose

The aim of the work is to show the practical application of MathCAD and MATLAB systems in the study of the mathematical theory of the reliability of radio measuring equipment using specific examples. With the help of examples of the theory of metrological reliability, MI will demonstrate the complex application of MathCAD and MATLAB programs for engineers and researchers in the field of mathematical methods of the theory of reliability.

Presenting main material

In article [10] computational methods of integration of discrete-continuous functions of metrological reliability are considered. Recursive functions of the mathematical theory of reliability and methods of integrating these functions are given. In this paper, on the basis of analytical expressions for recursive functions of metrological reliability MI are presented in [11], namely $p_{-m,k}(t)$, the probability of MI operation without metrological failure and $p_{m,k}(t)$ — the operation of MI with metrological failure in the MathCAD environment calculations were made and discrete-continuous functions of the metrological reliability of the MI were constructed, as well as a study of the behavior of these functions depending on the failure models and their parameters was carried out.

The use of the mathematical apparatus presented in the work allows you to calculate the conduct of the scheduled preventive repairs and the mode of self-checks. But this requires a more detailed consideration, which allows solving the optimization problem using rigorous analytical methods. A comparison of the reliability functions of diffusion distributions with exponential ones built in the MathCAD environment shows that the one-parameter exponential model overestimates the probability of metrological failure, which can lead to a significant error in the assessment of complex indicators of the reliability of the MI (Fig. 1).

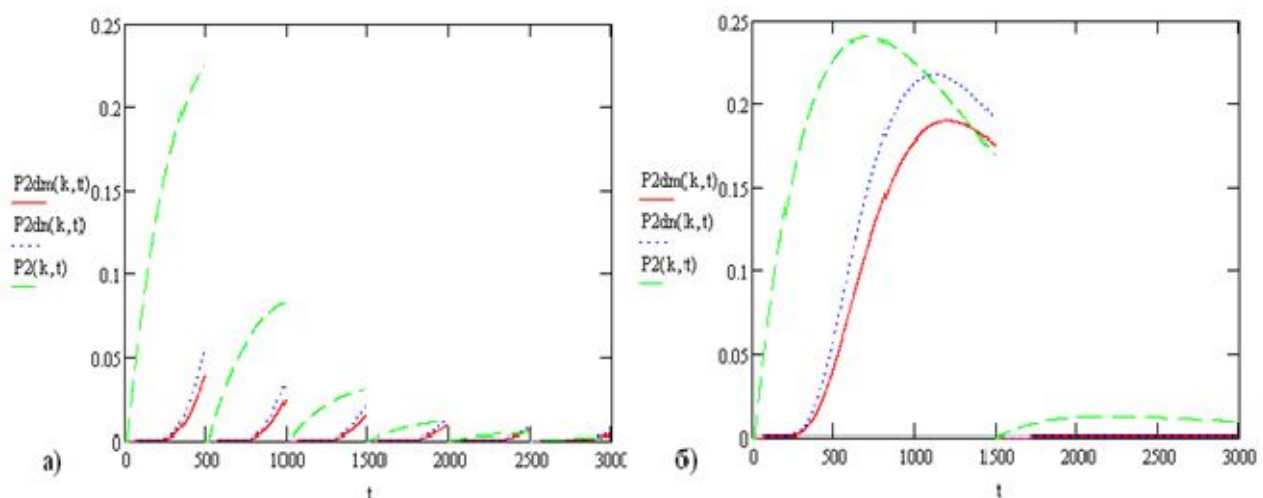


Fig. 1. Comparison of the functions of the probability of work with metrological failure for diffusion and exponential models of metrological failure (the case of ideal repair and verification) when: $T_u = T_m = 1000$ hours. (T_u — the control time for an undisguised (obvious) failure, T_m — the control time for a metrological failure) a) $T_n = 500$ hours., $v_m = 0,5$; b) $T_n = 1500$ hours, $v_m = 0,5$; (T_n — the inter-check interval at the given values of the metrological control indicators)

With the coefficient of variation of the working time per metrological failure $v_m = 0,25$ and the fixed parameters of the metrological control(MC) MI, the functions $p_{m,k}(t)$ of the input diffusion models of failures coincide with similar functions obtained for the normal model of metrological failure (Fig. 2), and at $v_m = 0,5$ the value of the probability of occurrence of metrological failure obtained for the generalized and truncated normal distribution distributions in the interval of the first interverification interval differ significantly, but in the ranges of subsequent interverification intervals the difference becomes insignificant (Fig. 3—4).

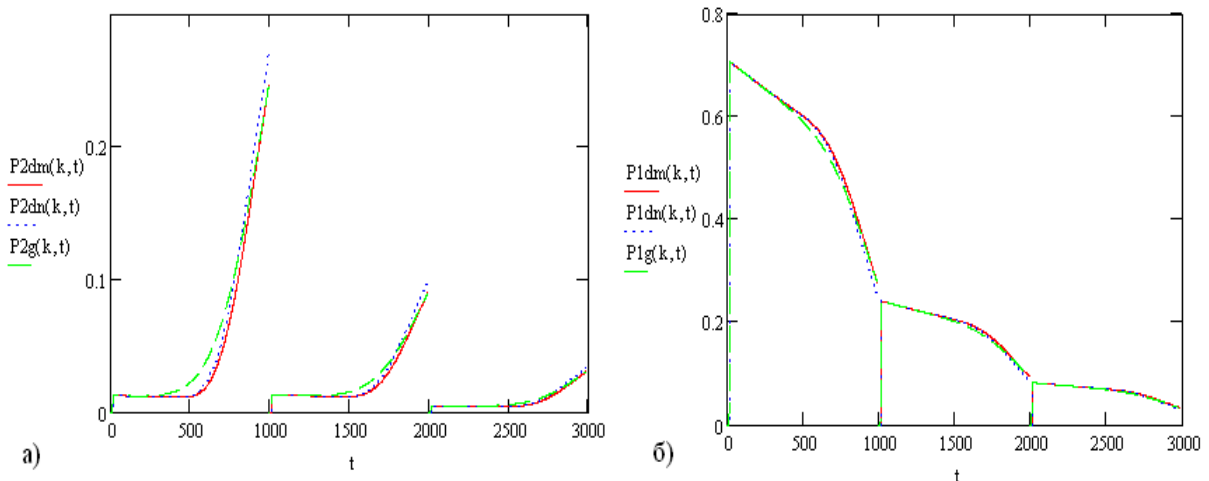


Fig. 2. Comparison of functions $p_{m,k}(t)$ (a) and $p_{-m,k}(t)$ (b) for normal and diffusion failure models (probabilities of errors against: $\alpha_v = \beta_v = 0,05, \beta_r = 0,25; v_m = 0,25, T_u = 3000\text{hours}$, $T_m = 3000\text{hours}, T_n = 1000\text{hours}$)

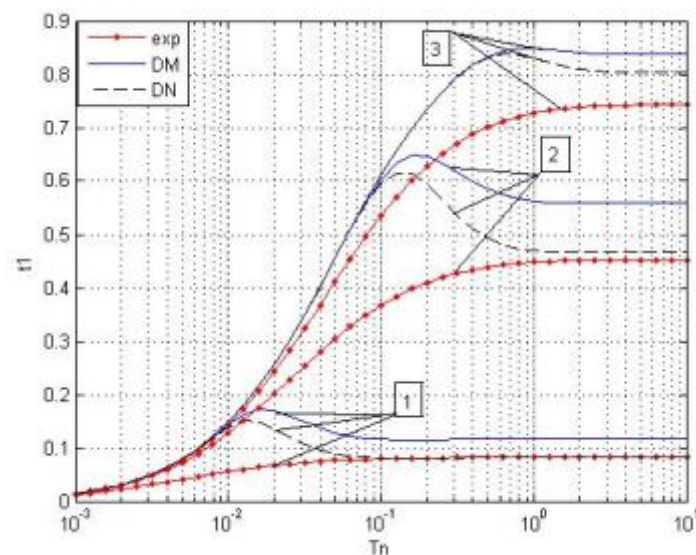


Fig. 3. Family of dependence curves of mathematical expectation of the total time of operation of the MI without failures $t_1 = t_1 / T_u$ ($T_u = 10000\text{hours}$) on the period T_n (logarithmic scale) for a series of values: T_m : 1—100 hours, 2 — 10000 hours, 3 — 46416 hours

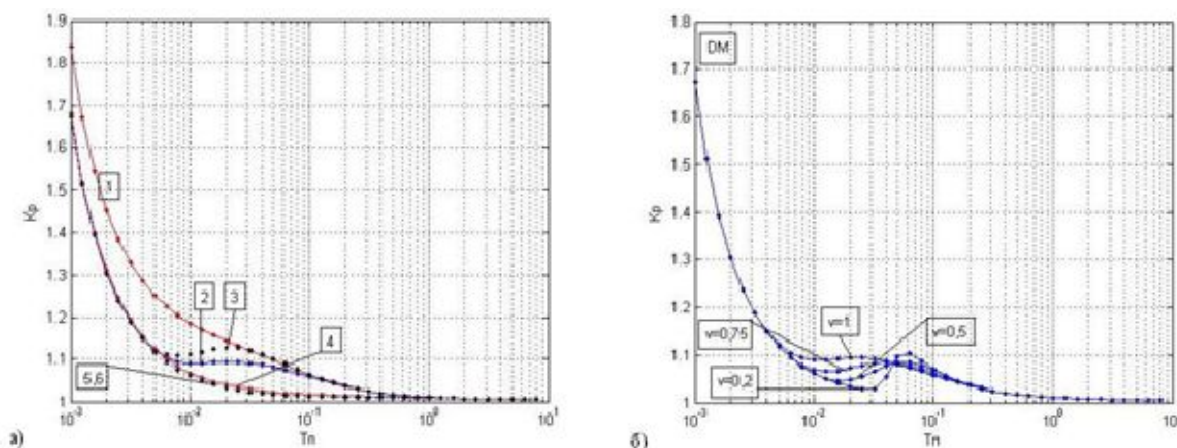


Fig. 4. a) dependence K_p on T_{mi} at $T_u = 10000 \text{ hours}$, $v_m = 1$, $\alpha_v = 0,05$, $\beta_v = 0,05$, $\beta_r = 0,25$; the designations of the curves $T_m = 464 \text{ hours}$ correspond to: 1 — exponential model; 2 — diffusion monotonic model; 3 — diffusion non-monotonic model, and respectively $T_m = 10000 \text{ hours}$ with curves 4, 5, 6.; б) curves of dependence K_p on T_n for a number of values v_m in the case of DM-models of metrological failures at $T_m = 464 \text{ hours}$

Use of MATLAB for computer calculations of the problem of analysis of discrete-continuous functions of metrological reliability of MI. The algorithm for the analysis of complex indicators of the reliability of the MI was implemented using the computer mathematics package MATLAB 7. This software allows you to calculate the integral of the reliability functions using special numerical integration functions with a specified precision (10^{-6} is automatically set), namely, adaptive Simpson quadrature and Gauss-Lobatto algebraic precision quadrature [10].

Comparing the results obtained using MATLAB allows you to conduct a mathematical study of the properties of the developed models, as well as to make sure of the reliability of the obtained results and the absence of errors when implementing the program within the framework in modern programming languages of database management systems.

Development of an algorithm for choosing the optimal reliability parameters and control period of the digital system of transmission and processing of information according to the criterion of economic efficiency (fig. 5).

The method of random undirected search consists in the study of solutions for the model of operation and MC MI by sampling the volume N of independently distributed numbers a_i^k , where l is the number of the parameter to be optimized, and $k = 1, 2, \dots, N$. The minimum and maximum values of the optimized parameters are entered, and a set of independent random vectors of parameters π_i^k is built based on the sequence a_i^k to find the optimum of the target function $CF(\pi, v)$.

An important task when using this approach is the generation of a vector of random numbers N of a given sample size uniformly distributed over the interval (0, 1). As an optimization criterion, we accept the sum of costs for the MC and losses from the use of MI with a parametric example:

$$CF = \frac{1}{k_{tu}} (C_{MI} + (C_c t_{34} + C_r \tau_p + C_p t_2) / T_c),$$

where k_{tu} is the coefficient of technical utilization; C_{MI} — the cost of the 1st hour of operation of the MI without taking into account the costs of the MO (conditional units(c.u.) /hour); C_c — the cost of 1 hour of inspection work (c.u./hour); C_r — the cost of 1 hour of repair work (c.u./hour); τ_p — is the time of verification of the MI; C_p — penalty for operation of MI with parametric failures (c.u./hour);

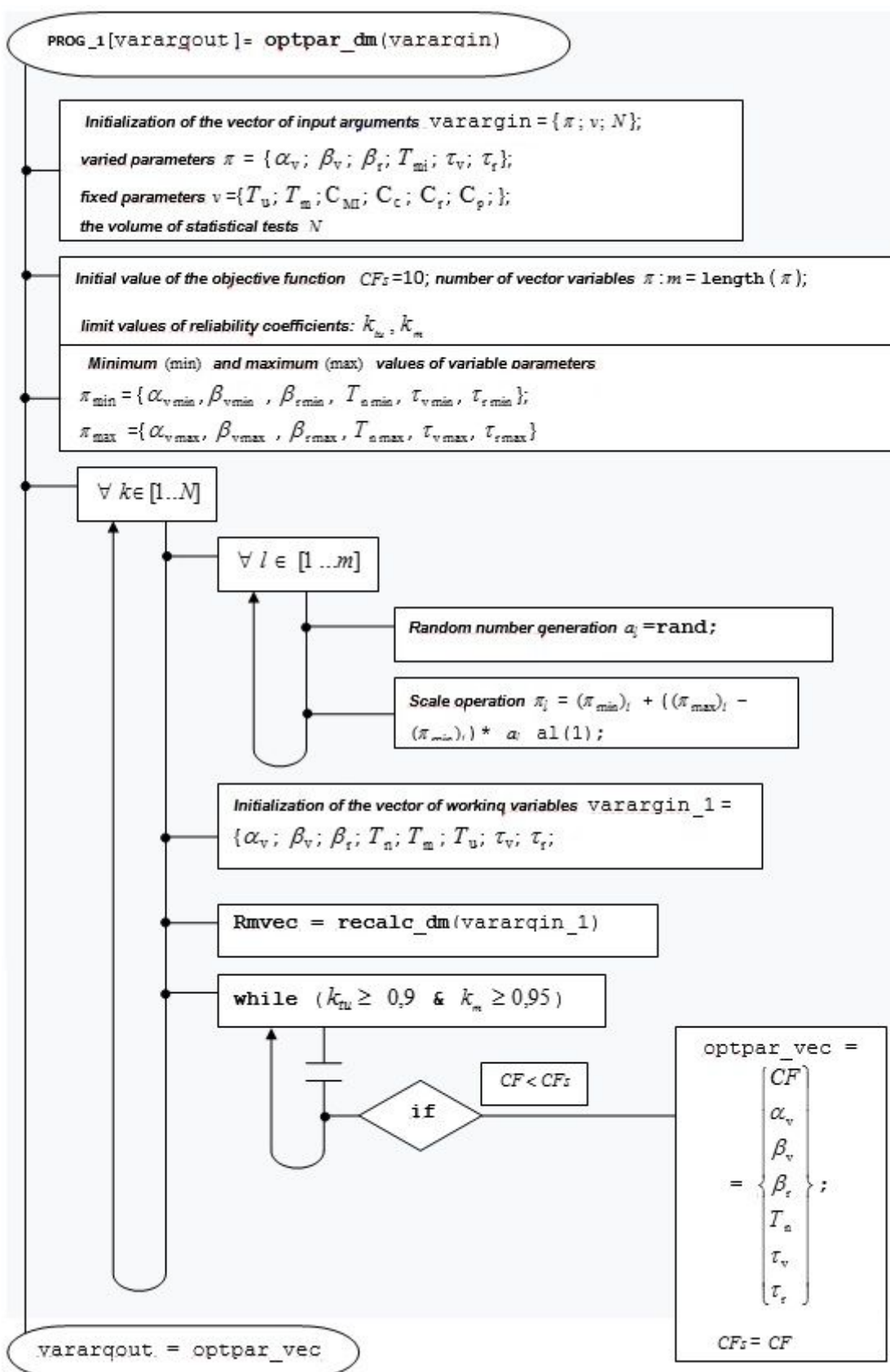


Fig. 5. Algorithm for choosing the optimal reliability parameters

t_{34} — mathematical expectation of the time of stay of the MI on inspections during the life cycle T_c ;
 t_2 — the mathematical expectation of the time of operation of the MI with a parametric failure in time T_c .

As a random number generator, a mathematical sensor of pseudo-random numbers was used, which belongs to the class of linear congruent generators (gamma period $(2^{19937}-1)/2$). For example, with the volume of statistical tests $N = 10^5$, the range of variation of the parameters of the MC MI is: $\alpha_v = \beta_v = 0,05 \div 0,2$, $\beta_r = 0,25 \div 0,35$, $\tau_v = 1 \div 6$, $\tau_r = 3 \div 8$; $T_n = 8 \times 10^4 \div 1,6 \times 10^5$, vector of combination of optimal parameters vector of combination of optimal parameters of MC MI $\pi = |0,0583, 0,0508, 0,2535, 8,0203e^{+04}, 2,5244, 6,4182|^T$ at the same time, the value of the objective function $CF(k) = 0,0602$ at the level of technical reliability $k_{tu} = 0,9651$ and the metrological component of reliability $k_m = 0,9651$, which confirms the efficiency of the developed algorithm (Fig. 5). With a sufficient number of tests and the use of modern methods for generating pseudo-random numbers, the optimal value of the objective function (criterion for the economic efficiency of the functioning of the MI) can be found using the proposed algorithm.

Conclusions

And its main advantage is an intuitive interface, which does not require programming skills, and the system uses familiar formulas. handles many analytical (symbolic) calculations. It is a multi-functional interactive computer system that allows, thanks to built-in algorithms, to solve analytically and numerically a large number of mathematical problems. Mathcad Workbook is an electronic book with live formulas, in which calculations are performed automatically in the order in which the expressions are written. It is distinguished by a simple and convenient interface, writing expressions with standard mathematical symbols. An example of a rather complex program is a program for solving a plane elastoplastic problem by the finite element method.

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