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STUDY AND COMPUTER MODELING OF DEPENDABILITY OF TECHNICAL OBJECTS

The paper describes methodologies, models and software for dependability assessment of various technical objects.

Keywords: *dependability, method, software, distribution, law, test, feature, variation series, reliability, failure, interpolation.*

Introduction

The development of modern engineering and technology in the past decade is carried out by great leaps. In addition to that, the problem of ensuring and improving the dependability of technical facilities (devices, instrument, equipment, technological systems, building structures, etc.), which work under the constant miniaturization of components and structures, different loads (thermal, mechanical, chemical, etc.), is particularly urgent. Dependability, as one of the main indicators of the quality of any products, largely determines the economic feasibility of its production. Solution of dependability problem is complicated by the fact that it is versatile and reflects the specifics of all the phases of existence of technical objects (TO) – from the design stage to operation.

Theoretical part

I. Aspects of dependability theory

The science of dependability emerged at the junction of several scientific disciplines, namely, the theory of probability and random processes, mathematical logic, thermodynamics, technical diagnostics, and others, the development of which is interconnected and is reflected in the development of the theory of dependability. Assessment and ensuring the dependability of not only the already mentioned TO, but of modern and automated control systems for TO of various purposes (process, undertaking, production, education, etc.) are among the urgent issues of the dependability theory.

The reasons for the manufacture of unreliable products can be such as the lack of regular compliance checks, mistakes in the application and improper control of materials during production, the lack of testing of materials for their compliance with quality and safety; improper accounting and reporting about controls, failure to comply with standards for the acceptance tests, the lack of instructions and guidelines for control.

Such directions as the technical dependability and operational dependability are distinguished in the area of dependability. Technical dependability is the starting point for the definition and calculation of up-state indices of TO and their elements, beginning with the design stage and finishing with manufacturing process. This ensures maintainability, substantiates durability, takes into account production and technological processes etc. [1].

The main objective of operational dependability is to develop and justify a set of measures to ensure the dependability of TO directly in their operation (work). These activities can apply methods for determining the dependability of real TO, to carry out forecast and immediate control of their technical condition, justify the amount and frequency of repairs, build a rational arrangement of the process of technical operation etc.

II. Objectives, methods and models for calculating dependability

The main purposes of the definition and calculation of dependability can include justification for the selection of a design solution, the confirmation or rejection of the choice of materials or elements, finding out the possibility and suitability of redundancy, etc.

Very often the idea of the TO dependability is formed upon actual data of laboratory, bench and industrial tests on the results of long-term observations of their operation in the real conditions. Based on these estimates, an appropriate distribution of random variables is selected, which is taken as the calculation model. Processing and generalization of this information is based on the probability theory, mathematical statistics, and systems analysis. Methods of optimization, forecasting, similarity, peer reviews etc. are also involved.

III. Dependability indices of technical objects

In the study of dependability of TO, engineers have to define some parameters with use of very limited amount of statistical data.

A quantitative characteristic of one or more properties constituting the dependability of the technical object is called the reliability index. Indicators of dependability include dependability, durability, maintainability, and survivability. Operational dependability is conditioned by reliability and durability of the most frequently failed components, and maintainability in terms of removal of random failures.

Because in some cases failures of individual components of objects do not mean a total loss of their operating capacity, the characteristics of reliability and maintainability are one-sided in this case, and dependability should be evaluated by overall indices (integrated dependability index).

The total number of such indices subdivided into the primary and secondary indices and regulated by the state standards is more than 70. This greatly hinders the formation of the requirements for TO dependability and their level control. As a compromise, domestic manufacturers embed a very limited number of key dependability indices in technical documents for TO. They are:

1. Reliability indices: the probability of failure-free operation, the probability of failure, failure rate, mean time to failure, failure stream parameter, mean time between failures.

2. Life characteristics (resource indicators): γ-percentile life, mean life; lifetime.

3. Maintainability indices: the average recovery time, total unit man-hours of maintenances, total unit man-hours of corrective maintenance.

4. Survivability index: the average survivability time.
5. Integrated indices: availability factor, utilization factor.

The problem of dependability of any objects is associated with the study of the phenomenon of failure. The functioning process of the restored object can be represented as a series of alternate intervals of operability and recovery after failure (Fig. 1).

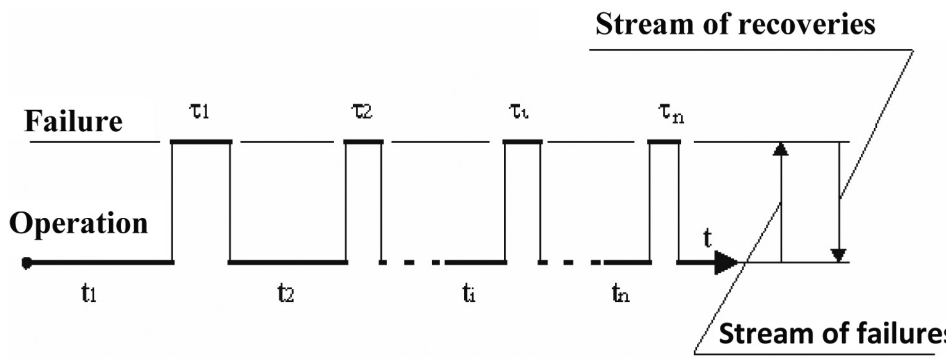


Fig. 1. Diagram of functioning of the recoverable object:
t1 ... tn are intervals of operability, $\tau_1 \ldots \tau_n$ are recovery intervals

Registration of the number and the time of failures allows us to obtain for each of the units the dependence of the failure rate λ on the time t. If the statistical evaluation of the experiment is divided by a sufficiently large number of equal time Δt for a long term, the result of processing of the experimental data is a graph shown in Fig. 2.

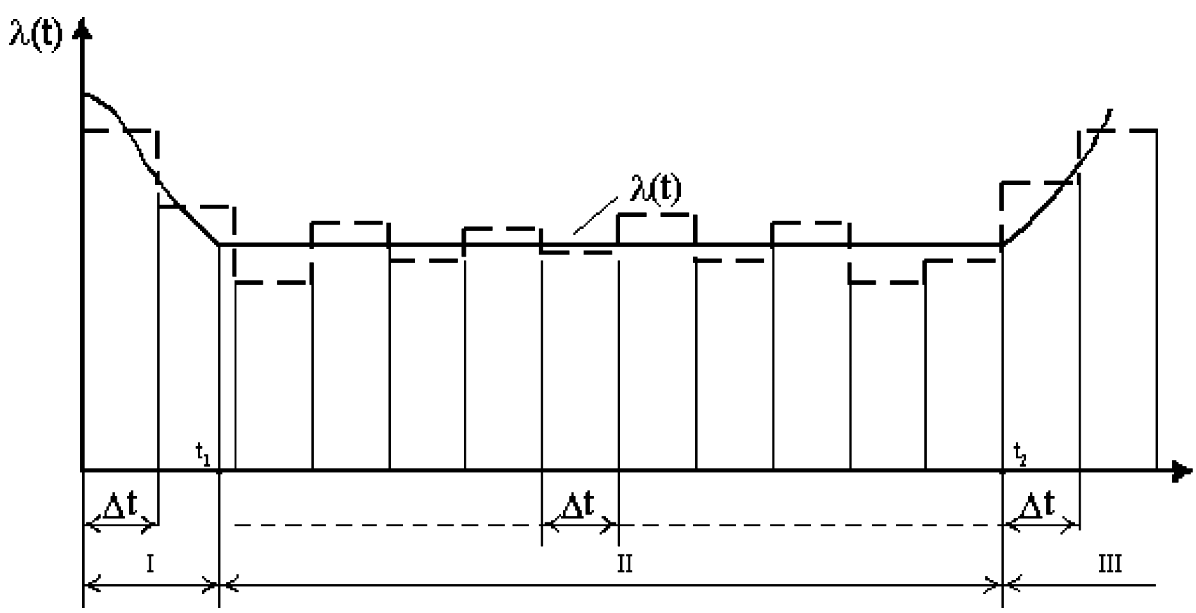


Fig. 2. The dependence of the failure rate on time
I is break-in interval, II is normal operation interval, III is aging interval

IV. Description of tests for dependability

Dependability tests are carried out using some specified unified program, which is their organizational and methodical basis. The program establishes the test plan (observations), methods of processing data obtained, the rules of decision-making [3,4].

The test plan defines a number of objects being tested (the most responsible task), duration and termination test criteria, the number of levels of control, the nature of action with failed objects (which have reached the limit state) – the replacement, recovery, etc. In most cases, these plans are standardized.

Collection of initial data to determine the dependability indices is carried out visually, using special time meter of operating time, counters of the number of switching on, etc., as well as on the basis of maintenance and repair register logs and logs of requirements for spare parts, the account of the mechanisms' operation and records of operating time and failures, etc.

Decision-making based on the results of tests is carried out by established rules that from a mathematical point of view are indicator functions taking the values 1 or 0. A positive solution of (1) is compliance, and a negative one (0) is non-compliance of controlled indices to specified requirements (standards).

Currently, at the definition of dependability and durability of TO three sources of information is used: definitive tests, routine check tests, operational tests in production conditions.

Definitive tests allow us to set the nominal values of the dependability of new equipment, which are placed in normative documentation.

Routine check tests are carried out on the basic serial TO for the conformity assessment of the actual values of dependability indices to standards' requirements or specifications. The method of routine check tests for dependability are carried out periodically, and in the general case it should contain a list of dependability indices to be controlled, and the following data for each specific index of dependability: acceptance and rejection level, the risk of a manufacturer and the risk of a customer, the number of test specimens, the test time for each of them, the permissible number of failures, the method of testing, a test plan, a list of parameters that characterize the condition of TO; test conditions (level of influencing factors and their values, sequence and duration of their effect, etc.), the decisive rule (acceptance or rejection of a production lot).

There is a rule established at testing that must be followed at each stage of the experiment in taking one of the three decisions: to accept the basic hypothesis, to accept a competing hypothesis, go on with further tests. Choice of three critical areas in decision-making is based on the analysis of the sequential likelihood ratio test.

V. Body of mathematics for the study of dependability of technical objects

Since the dependability calculations are mainly carried out at the design phase, it allows us to choose the most suitable option of construction and methods to ensure dependability and to identify "trouble spots", reasonably assign operating modes, the form and the order of TO maintenance.

Calculation of dependability can consist of the following stages:

1. Determining a composition of defined dependability indices.
2. Selecting a method for the dependability calculation.
3. Working out a mathematical model.
4. Carrying out calculations, analysis of the results, and adjustment of the calculation model.

A very important task is a quantitative assessment of the hypothesis that observation results belong to any law of distribution. To make a decision on this issue, there are fitting criteria, the most common and effective of which the fitting criterion of Pearson and Kolmogorov. In general, the method of determining the resulting characteristics of the distribution law under study consists in the following.

1. A set of statistical data is obtained by experimenting, and then it is written down in the form of a variance series.

2. The experimental data are plotted on the coordinate grid distributions (exponential, normal, Weibull, etc.).
3. The possibility of linear interpolation of the experimental data is defined.
4. The maximum deviation of experimental points from linear interpolation is found out and checked by fitting criterion of Kolmogorov.

Computer simulation is the most effective means of dependability analysis of complex systems. Two algorithms for modeling are widely disseminated: the first is based on the modeling of the physical processes occurring in an object under study (dependability evaluation is then determined by the number of parameters of the object going out of tolerable limits), the second is based on solving systems of equations that describe the state of the object.

Analysis of physical and chemical processes also provides a possibility to obtain the estimate of dependability of TO under test because it is often possible to establish a relationship between dependability and the condition and the character of the physical and chemical processes (the relation of strength and load, wear resistance, presence of impurities in materials, change of the electrical and magnetic characteristics, noise, etc.).

Practical implementation of the task

Processing of the results of routine check tests and definitive tests and dependability indices calculation is a difficult and tedious task. One way of tentative model development to facilitate visualization of the data structure is to construct a functional diagram indicating the external entities, data flows, and the designation of all key processes in the AllFusion ERwin Data Modeler (Fig. 3).

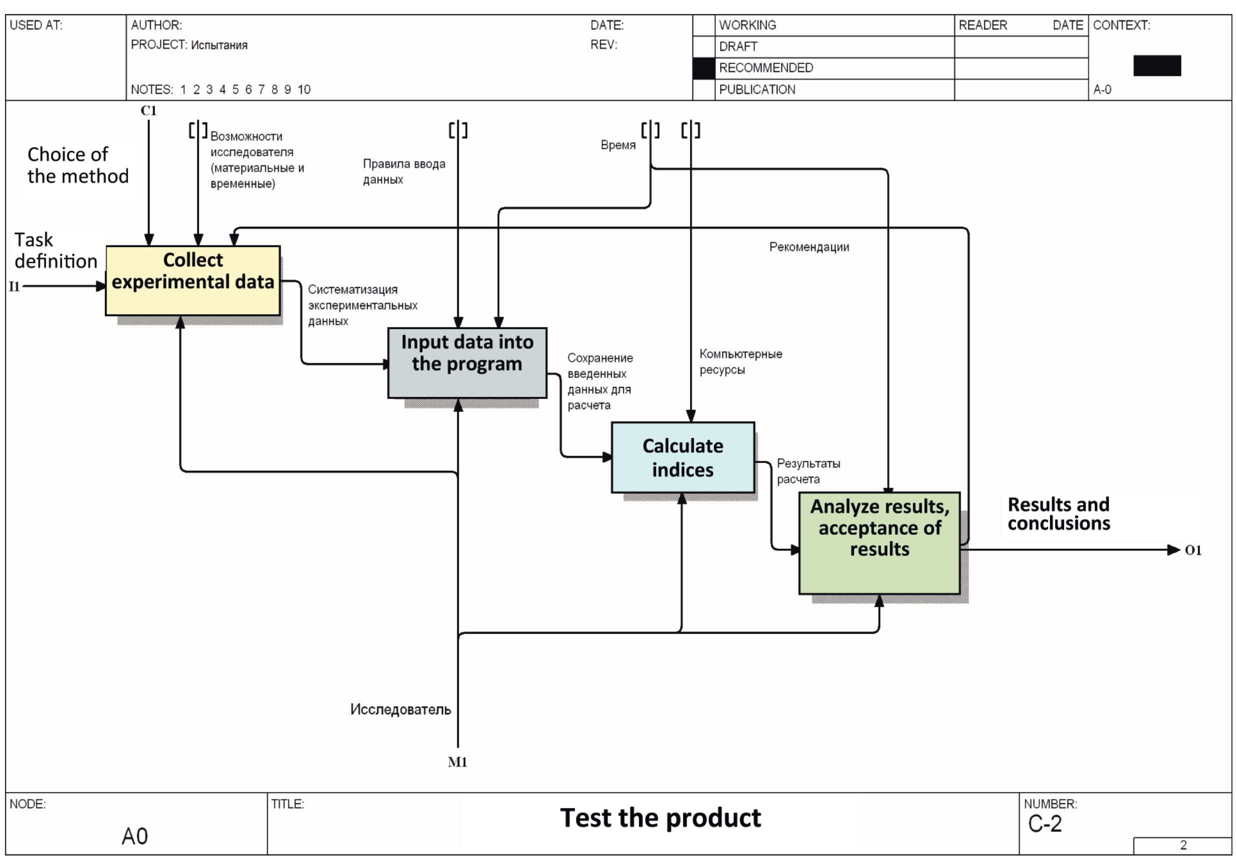


Fig. 3. Functional diagram

Based on this diagram, the program “DeviceTest” was developed in rapid application development environment Embarcadero RAD Studio XE3 for processing and interpretation of test results. [5] The program allows us to carry out investigations and calculation of the following types:

- To check the sufficiency of test data of technical (and other) facilities;
- To determine the type of the distribution law.

To determine the type of the distribution law, it is necessary to enter the number of tests performed and the data obtained experimentally. After that, we activate the process of input data interpolation for to the first type of the distribution law, i.e. the exponential one (Fig. 4). If the automatic interpolation does not satisfy the user or the fitting criterion of Kolmogorov is not met, it is possible to implement the interpolation of data “manually” (Fig. 4).

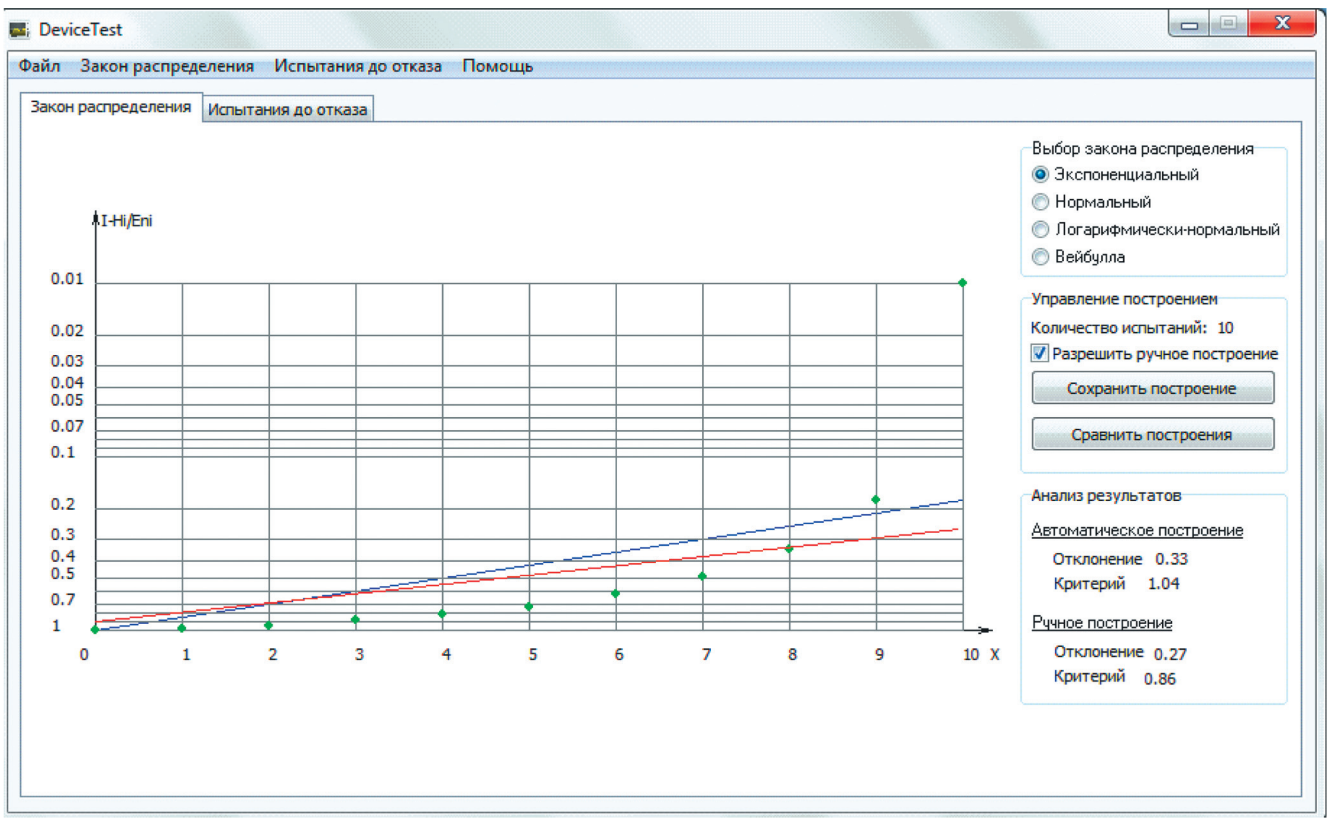


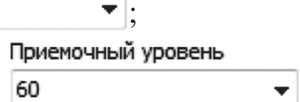
Fig. 4. The result of the interpolation (automatic and manual) for the exponential distribution law

The results of linear interpolation by different distribution laws can be compared for the possibility of subjective researcher choice of one of them (Fig. 5). After determining the type of distribution, it is possible to solve many problems for the evaluation and assessment of dependability indices.

To check the sufficiency of the test results, the following initial data is used (Fig. 6):

Supplier’s risk ;

Customer’s risk ;

Acceptance value of MTTF T ;

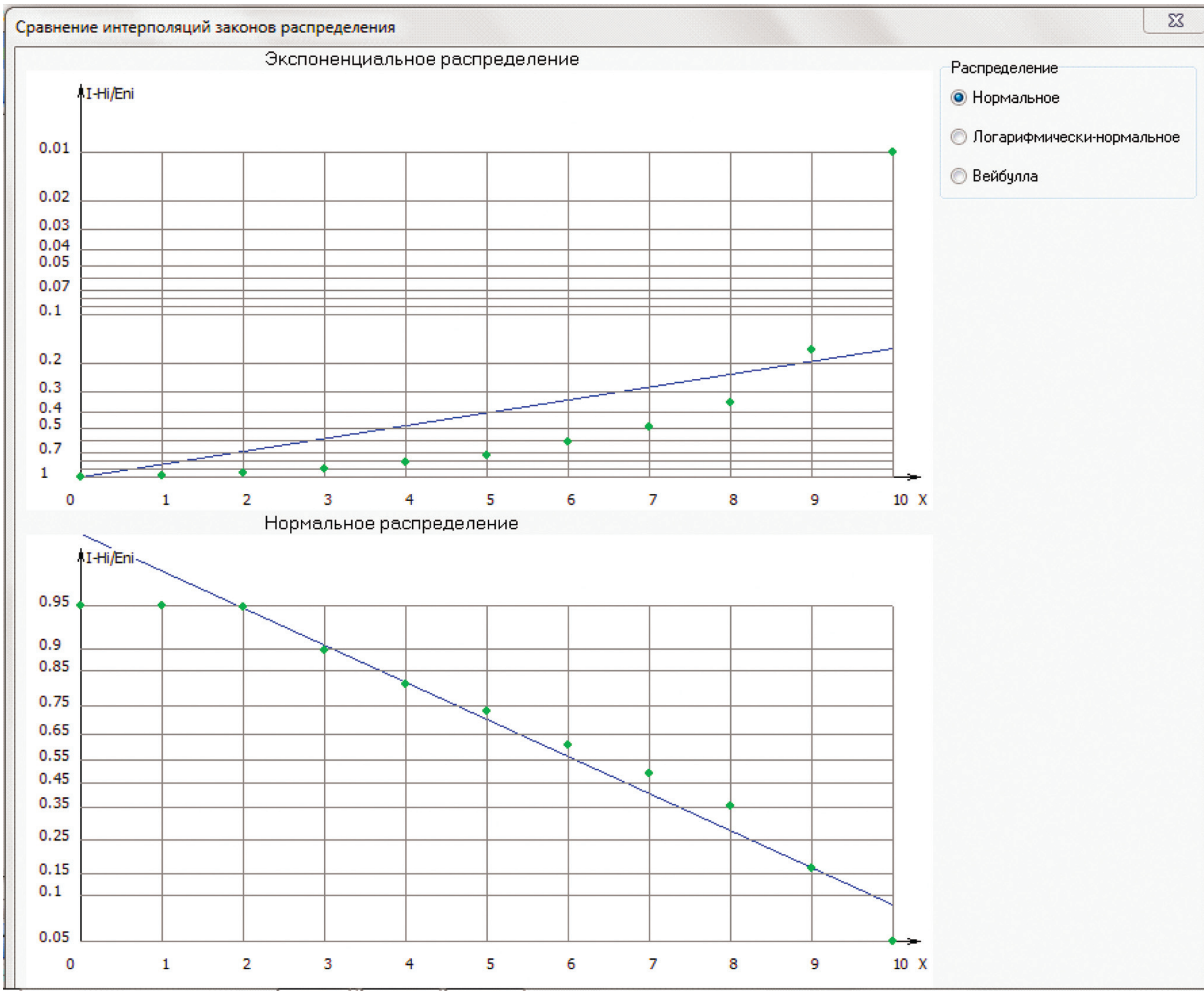


Fig. 5. The window to compare the results of automatic interpolation

Rejection level of MTTF T [Браковочный уровень: 30];

Truncation of the test results by the number of failures myc [Отказы: 16];

Truncation of the test results by time tyc [Наработка: 11].

In addition to that, obtained experimental indicators interesting for researchers are introduced (e.g., the number of failures per time period). Decision to truncate (restrict) sequential analysis is made in advance. In this case the method involves the simultaneous testing of all samples with the fixation failures when they occur.

Truncation parameters myc and tyc are defined by the tables in GOST 27.410-83 or imposed by the researcher. After plotting a message box, there appears a window that displays the message about the results of the construction plan of successive tests (Fig. 6).

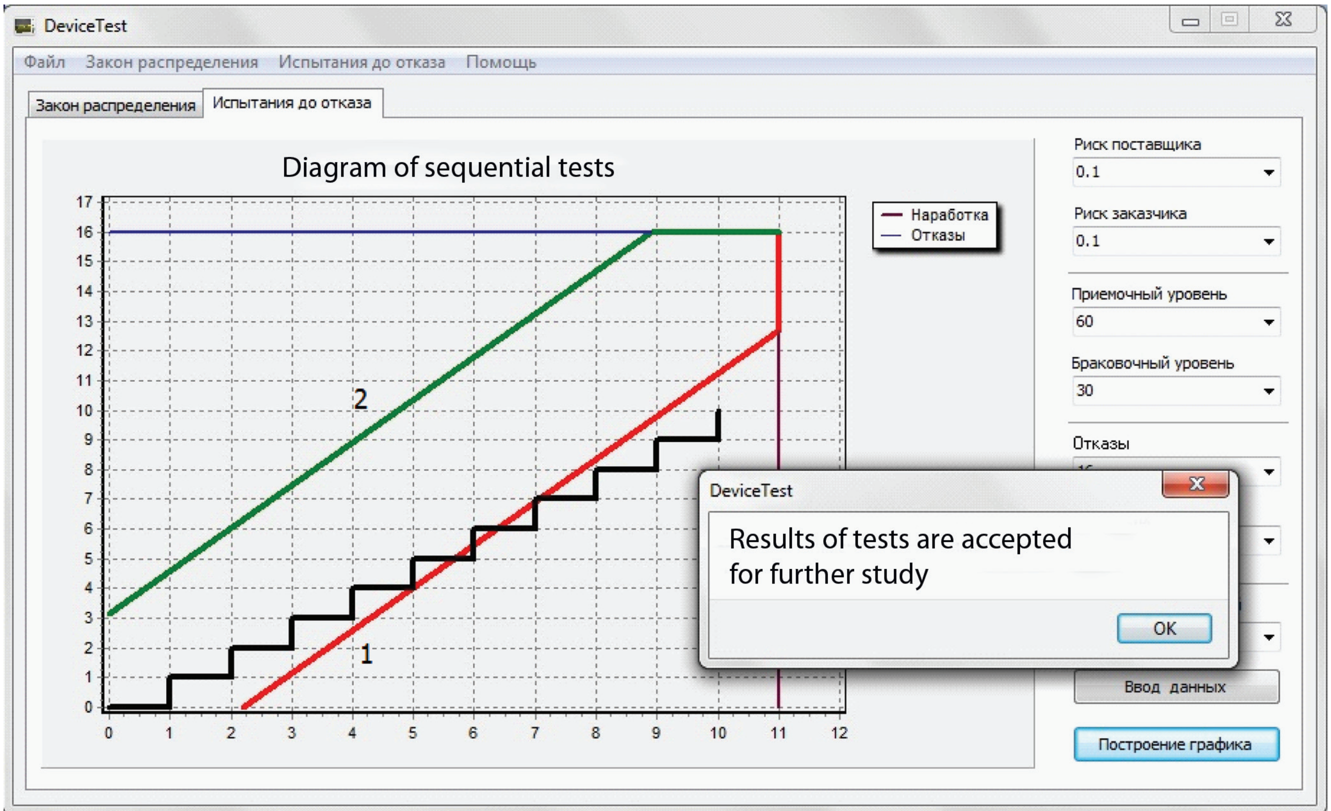


Fig. 6. Test data of sufficiency timing by sequential method
1 is the line of non-conformity, 2 is the line of conformity

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