Reliability Basics of Information Systems

Edited by Alexander Petrov

AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY PRESS KRAKOW 2016

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Introduction

Scientific and technical mission targeted to insure technical systems reliability occupies central place in all systems life cycle stages and comprises a wide range of designing, technological, physical, chemical, mathematical, modeling, experimental, organizational, economic and other research areas in various fields of science and technology. The level of systems reliability may serve as an integral feature of their operation. Reliability problems were, are and will be relevant and important in the process of technical systems development. Special problems of reliability are important at the present stage of technical systems evolution, which, after the industrial stage of development today is considered as informational, taking into account the described below facts:

- now it was enlarged the integral complexity of engineering systems, herewith such systems are basically hardware-software or rather apparatus-information complexes,
- expanded range of executable functions, significantly increased their role in various domains of systems use, including the field of economy, science and technologies,
- extensive use of computer technology, modern information technology has contributed into significant enhancing the potential of modern hardware and information systems, for solving various tasks,
- in publications on reliability were expanded, along with the traditional, multitudes of reliability characteristics, such as devices metrological reliability measurement characteristics etc.,
- in the second half of the twentieth and early twenty-first century it was accumulated vast experience in technical systems reliability research, especially at hardware systems reliability study,
- research regarding the reliability of "soft equipment" hardware and information systems – information, including mathematical and software systems has began to be conducted intensively in the late twentieth and early twenty first century, and there were obtained important results,
- despite the increasing role of the technical systems reliability issue, today, due to various reasons, primarily due to the lack of adequate funding, the number of publications on the reliability and the corresponding dynamic implementation of its results into practice for the creation of highly reliable systems has decreased in comparison with the preceding periods.

Fundamentals of reliability lay in examining the quantitative characteristics (criteria) of information systems reliability, in exploring the relationship between indexes of economy, efficiency and reliability and are based on the development of methods:

- tests on reliability, methods of its conducting and results evaluation,
- reliability and optimal regimes of preventive (routine) activities control at the systems operation, methods and rules grounding items replacement norms,
- setting of modes and selection of functions that provide optimal reliability, methods for optimal designs and patterns selecting, that provide required components and elements reliability, best practices for failures identifying in systems.

Reliability is a property of a system to retain its basic characteristics in time and space within the preset modes and conditions of use, maintenance, storage and transportation. Depending on the purpose and the conditions of facilities operation the reliability items include failure-free operation, durability and maintainability preservation and as the major reliability characteristics – probability of time between failures appearing, technical resource lifetime.

It provides the basics of information systems reliability, which is the major class of technical systems as of apparatus-informational systems. Presented in this book material reflects the implementation of the following objectives:

- fundamentals substantiating of technical systems reliability as of science,
- put in use the accumulated during significant time intervals results of technical systems reliability performance research at all stages of systems life cycle,
- to adapt the major directions of information systems reliability research as of hardware-information systems to the stages of systems life cycle.

Publications on the systems reliability can be distinguished onto two following groups:

- the content and the materials of the first group reflect the specifics of studies on reliability calculation, reliability characteristics of typical elements, modules and subsystems at different stages of their life cycle,
- the second reflects the reliability research methodology regarding modern hardware and information systems at all stages of their life cycle.

This paper can be attributed to a greater extent to the second group of research publications.

The book is intended for researchers, professionals and university students who study the field of “Security of Information and Communication Systems” within discipline “Reliability of hardware-software systems.”

1. General issues of technical systems reliability

Below are considered the original concepts, terminology and definitions regarding the technical systems reliability as of science. In the materials on mathematical apparatus reliability principles are currently covered only the basic scientific and technical research areas of natural and engineering sciences and are given the reliability theory axioms.

There are shown also the major provisions of modern scientific and technical problems in research of reliability at all stages of technical systems life cycle, the basic class of which is a class of information systems [1–11].

1.1. Technical systems reliability basics as the science

The beginning of scientific and technical research of technical systems reliability formation is attributed back to the 30s of the twentieth century. The development of technical systems during the Second World War, in the 50–80 years of the "cold war", space exploration, implementation of nuclear technology has greatly contributed to the technical systems reliability interest growth in various fields of science and technology. During this period were published a large number of papers on reliability.

We shall give the following information about the technical systems reliability that objectively might be called classic or basic.

In scientific publications, in the state standards, exist diverse definitions of the technical systems reliability terms, but in our opinion the most suitable definition is as the following.

Reliability is property to maintain in certain time limits a set of values for all the facilities of system that ensure its ability to perform the required functions in specified modes and conditions of use, maintenance, storage and transportation.

Further it can be observed that reliability is a composite property that, depending on the purpose and the requirements of its application, may include items of reliability, durability, maintainability and preservation or some combination of these properties. This definition is used only for general descriptions but not to quantitative specified properties.

We know that today there is no singular particular definition of reliability. So in the International Standard IEC 50 (191) the "Reliability" (trustworthiness) is considered as a generic term that is used to display non quantitative properties of reliability, maintainability, and software maintenance. In this case, the property "longevity" (durability) is treated separately and is not included in the term “reliability”. In glossary EOKK (EOQC Glossary-Bern, 1988) the “reliability” is also considered as a generic term used to describe the non quantitative properties such as reliability, durability, maintainability and reliability at preservation and transportation of engineering systems.

It should be included several comments to the fundamental works on the reliability that are relating to the definition of “reliability”. It follows from these definitions that reliability is an intrinsic property of the system embedded in it during the manufacture and manifested for the duration of operation. To compute the reliability, as well as any other properties of the system, we need this or that quantifying measure which can be its characteristic. Reliability yet cannot be reduced to any one of these characteristics.

The similar definitions of reliability are given in other works. For example, the terminology of metrology dictionary provides the subsequent definition.

Reliability – system’s intricate property which in general is reflected in its reliability, durability, maintainability and preservation.

These properties in the definition of engineering system reliability are multifaceted; they proceed in time and space, appear at all stages of the system life cycle and are dependable on the large number factors actions. Therefore, at present, to determine the quantitative reliability characteristics are mainly used probabilistic models and their, based on tests, statistical evaluation by means of mathematical statistics methods. Using the normalized probability measure to determine the quantitative reliability characteristics formulates the fundamental statistical method for the study of reliability.

The reliability characteristics of products that can be called classic and are functions of time, include:

- time to failure probability for a given period,
- mean time (working hours) in period till the first failure,
- failure rate,
- failure flow characteristics, etc.

Here is presented a number of well-known definitions in reliability theory.

The reliability theory – a modern branch, and as such it has not yet emerged as a science, it has arose from the needs of practice due to the rapid technological progress and especially due the emergence of sophisticated electronics and automation systems with a large number of elements. It studies:

- reliability criteria and quantitative characteristics,
- methods of reliability analysis,
- methods for the synthesis of complex systems according to the criteria of reliability,
- methods to improve reliability,
- methods of equipment reliability testing,
- scientific methods of equipment operating creation according to its reliability (preventive maintenance modes grounding, spare elements norms, methods of faults finding, methods of collection and statistical data analysis in relation to equipment failures).

It should be borne in mind that the reliability theory is an independent science, and not a separate section of the theory of probability. It is a technical rather than a mathematical discipline, and the range of tasks solved by it is not limited to the probability theory problems.

Prominent soviet scientists in the field of reliability Y.K. Belyayev and Gnedenko B.V. have given in the mathematical encyclopedia the subsequent definition.

The reliability theory – engineering itinerary of mathematical methods implementation, within which are developed:

- methods of technical systems reliability calculating,
- methods for assessing the manufactured products reliability,
- ways to optimize and improve the efficiency of sophisticated technical systems and their constituent elements at its operation, including also such concepts as the storage and transportation.

If we consider the reliability principles as a science, then within the denotation of the Great Soviet Encyclopedia, such science satisfies all claims attributed to the technical sciences, since reliability principles are:

- the area of human activity, function of which is to create and theoretically systematize the objective knowledge about technical systems in various domains of utilizing,
- this domain augments to the productive power of society,
- it is closely related to the natural sciences, including the sectors of economy and, through the production which ensures the material life of society, to the social sciences.

Fundamentals of reliability as of science consist of:

- the legal structure that ensures the unity of scientific and technical systems reliability problems of varying complexity solving at all stages of theirs life cycle,
- reliability theory,
- the applied basics of reliability, using numerous natural sciences and engineering methods to solve technical systems faultlessness, durability, reparability and preservation reliability problems.

Summing up, it should be noted that at present the relevance and importance of scientific and technical issues of technical systems reliability did not decline, but had enlarged its significance.

Nowadays we have an objective basis of numerous examples of the development and effective use of technological systems in different sectors of the economy, science and technology, making possible to examine the foundations of the technical systems reliability as of a science that meets all most wanted requirements.

Fundamentals of reliability – the science about the subject of technical systems reliability, durability, reparability and preservation of varying complexity technical systems at all stages of theirs life cycle.

This definition of technical systems reliability basics as of science, in fact only highlights the key strategic research areas of technical systems of whichever complexity; those in each particular case determine modeling and using the results of a wide range of theoretical, simulation and experimental reliability research problems solution.

1.2. The primary concepts, terminology and definitions of reliability basics

Basics of technical systems reliability, like of any science, use the specific system of initial concepts, terms and definitions. It should be noted that at present it is carried out the international harmonization of standards regarding the technical systems reliability, with active participation of Ukraine, for forming a coherent system of terms, definitions (in some cases such system is called term-systems). In formulating of these definitions mentioned above are used such sources as national standards of Ukraine, fundamental works on reliability [1–9].

Object and types of objects. Term "object" is shared in many various complexity technical systems.

Object – system, structure, mechanism, subsystems, equipment, functional units, devices or item or any of them, considered in studies of reliability as an independent element.

It is noted also that the object idiom can include hardware, technical personnel, or any combination thereof.

A compound of objects, united by a common purpose and the purpose of an operation, may also to be considered as an object.

Therefore, in the further text, the terms object, item, technical system, information system will be used interchangeably.

The following definitions together with the definition of an object, in fact make it possible to carry out the required classification of objects and their properties.

Function (of object) defined function (of object) is performing within an object a process that meets its purpose, identifying the desired conditions or properties of an object according regulatory requirements and (or) design (construction) documentation.

The primary function, requisite function is a function or set of functions of the object, as its performance is seen as an obligatory condition for matching the object to its assignment.

All functions of an object can be roughly distinguished into primary and secondary. Auxiliary functions are functions whose failure does not affect the compliance of an object to its assignment.

Among the objects are distinguished the described below item types.

Repairable items; repairable object – an object whose repair is possible and provided by regulatory, repair and (or) design (constructional) documentation.

No repairable object – an object whose repair is impossible or not anticipated by regulatory, repair and (or) design (constructional) documentation.

Renewable object – repairable item, which after failure and fixing its problem becomes once more able to perform the required functions according prescribed quantitative reliability characteristics.

Nonrenewable object – an object whose repair is not possible or its operability cannot be recovered according the prescribed quantitative reliability characteristics.

Items restored after the occurrence of failures are renovated and continue to operate. Nonrenewable objects operate until first refusal.

Serviced object – the object maintenance for which is provided by specifications and technical documentation, and (or) by design (constructional) documentation.

Unserviced object – the object, maintenance for which is not provided by specifications and technical documentation, and (or) design (constructional) documentation.

Properties of objects. Below we consider the basic reliability properties of objects [2, 6, 7, 9].

Earlier it was noted that reliability is a complex property, which, depending on the object goal and conditions of its use may include failure-free, durability, maintainability and preservation or some combination of these properties.

Reliability as a generic term is used only for general descriptions of nonquantitative specified properties. Because of that, below are described some definitions.

Faultlessness – a property of an object to perform the required functions under certain conditions during a specified interval of time or "time to failure".

Durability – ability to follow the object functions through the time interval before transition to the ultimate state during the period of the system maintenance and repair.

Preservation – ability of object to be retained in the set of values characteristics that define an object's ability to perform the required functions at operation, during and after storage and (or) transport.

Maintainability – ability of an object to be adapted to its technical state maintenance and restoration at which it can perform the required functions provided with the adequate maintenance and repair.

Readiness – a property of an object to be able to conduct the required functions at specified conditions at any time or during a specified time interval, provided that it encompasses the required external resources. This property depends on the combination of the maintainability, reparability and software maintenance reliability properties.

State of the object. Commencing from the position of reliability an object can be found in the following technical states: operable (functional status), faulty (inoperable), critical condition and ultimate condition.

Serviceability – the state of the object on which it is able to perform all functions specified.

If one of the demands of the facility does not meet the regulatory, technical and (or) design (constructional) documentation, then the state of an object is regarded as a fault.

Fault – state of an object in which it is unable to perform at least one of the specified object functions. The fault is often the result of the object failure, but it may emerge without it.

Working state, efficiency – the state of an object, which is characterized by its ability to perform all required functions.

Inoperable, disabled – the state of an object on which it is unable to perform at least one of the required functions.

Critical state – the state of an object that may cause injury, significant property damage, or other abnormal effects.

The critical condition is not always the result of a critical failure of a particular item it should be set the critical condition criteria.

Boundary state – the state of the object at which its further use is unacceptable or impractical and restoring of its operable condition is impossible or impractical.

The boundary state occurs, when the characteristic failures flows become unacceptable, and (or) object becomes non repairable due to a malfunction.

Object transfer into boundary state leads to suspension or complete cessation of facility operations. At reaching the boundary state the facility is either removed from service, or sent to a medium or major repair or is deducted or transferred for the disposal or for other purposes.

Vitality (durability) – a property of an object to maintain limited performance in the conditions of external influences that lead to the failures of its components.

Vitality describes the property of an object to resist critical failures at any conditions, including those that are not provided by documentation.

Safety – object property to ensure that there is no risk of damage to human health, property or the environment.

Failure modes. Here we will focus on one of the most important definitions of functioning, namely according the basics of technical systems reliability [8, 9].

Refusal – an event which is characterized by the loss of ability to perform the desired function as a result of object working state violation.

"Failure" is an event unlike the "malfunction", which is the prerequisite and the cause of failure.

If the object performance is characterized by a set of values of certain technical characteristics and parameters, the indicative of a failure is the value of one of these parameters exit beyond the tolerances. In addition, into the failures criteria should also be included qualitative signs that indicate a malfunction of an object.

Failure criteria are to be distinguished from damage criteria. Criteria of damage mean a feature, or a set of traits of faulty, but workable state of an object.

Partial rejection – denial that leads to a failure of a facility to perform the required functions.

Complete failure – failure that results in complete inability to perform any item required functions.

Resource denial – rejection due which the object reaches its ultimate state.

Severity of failure – a set of functions that characterizes the consequences of failure.

Denial of one the same object can be interpreted as *critical*, depending on whether the object is considered as a single or it is a part of another object. Insignificant refusal of an object which is a part of a more responsible object can be seen as an essential and critical, depending on the consequences of a composite object failure. For the classification of consequences it needs criteria and causes of failures analysis and then a building of logical and functional connection between events of failures.

Classification of failures, according its consequences, is essential for the reliability rationing (for a reasonable choice of range and numerical values of the normalized reliability characteristics) as well as during warranties setting.

Critical denial – denial that by judgment could result in personal injury, significant property damage or other unacceptable outcomes.

Sudden denial – refusal that cannot be predicted prior of examination or at technical inspection.

Phasing denial – failure caused by gradual changes in the values of one or more characteristics of the object.

Phasing denial can be predicted by prior study or inspection; sometimes it can be prevented by maintenance actions.

In some cases it is possible to differentiate the sudden and gradual failures onto such two classes that allows, depending on the given possibility, to predict the time of failure. Unlike the sudden failure, the dynamics of phasing denial is in continuous and monotonic change of one or more characteristics that describe an object's ability to perform the required functions. This allows to prevent the emergence or failure and to take measures to eliminate (locate) its adverse effects.

Malfunction – self removing type of failure, or temporary refusal regarding that an operator can eliminate its interference.

A typical example of malfunction is information system stopping; the eliminating of malfunction can be done by restarting the program from its stop or restarting it from the beginning.

Constructive failure – failure caused by imperfections or violations of the set rules and of (or) design standards in the facility construction.

Production denial – rejection, caused by a facility manufacturing mismatch to its design or to the standards of the production process rejection, caused by a facility manufacturing mismatch to its design or to the standards of the production process.

Classification of causes of failures in relation to production or constructive denial is introduced to determine at what the object life cycle stage actions should be taken to prevent the malfunctions.

Component element failures can also be as a result of design, as action of both manufacture and occurred at operation.

Degradation denial is a refusal caused by degradation process in the system subordinated yet to all rules of design, construction and operation.

During the reliability analysis is distinguished initial failure when there found defects influences not detected during manufacturing, testing and (or) receiver control, and later or degraded failures. The last are revealed at the final stage of a facility service operation as a result of natural material fatigue processes, wear etc., or when the object or its component parts are approaching the boundary state in case of physical deterioration. The probability of degraded failures occurring during the planned and overhaul terms of service (of resource) must be sufficiently small. It is provided with the longevity expectation calculations based on the physical nature of degraded failures, at proper maintenance condition.

Mechanical, physical and chemical processes that make the causes for refusal usually proceed over time rather slowly. Below are given definitions such as fatigue, wear, corrosion, aging and degradation:

- fatigue (of material) – a process of gradual accumulation of material damages under variable stresses that leads to changes in properties, e.g. cracks formation, its development and destruction of material,
- wear – the destruction at separation of material from the surface of a solid object and (or) its accumulation in a residual deformations during friction, which manifests itself in a gradual change of size and (or) the form of the object,

– corrosion – the destruction of a metal object surface due to chemical or electrochemical interaction with the active medium (aggressive atmosphere, solution of acids, alkalis, salts etc.),
– aging – gradual irreversible changes in the object properties caused by chemical and (or) physical processes that occur spontaneously in materials,
– degradation, degradation processes – an action of one, or several natural processes of aging, corrosion, wear, fatigue and fracture combination.

Reservation. One of the major ways to improve the technical systems reliability is the redundancy (reservation) which as a way of an object reliability ensuring by the use of additional tools which are redundant in relation to the certain required with respect to the minimal operating functions [2, 8, 9].

As an additional means and (or) capabilities implemented for reservation (reserve) there used: backup of elements in the structure of the object (structural redundancy); backup using reserve time (temporal redundancy); reserving with a use of information reserves data (informational backup); backup, which uses the ability of the object elements to perform additional functions (functional redundancy); backup, which uses the object elements ability to accept more of top nominal load (loading redundancy), etc.

Information technologies. The above mentioned terminology is common in the studies of technical systems reliability and mainly describes the hardware systems. In this paper, the major object of study is the information system whose composition along with the hardware is a part of the so-called "soft hardware", which include information provisions: physical and mathematical models of the system to perform the required functions, algorithms and software. It is known that the study results of the hardware reliability were accumulated during the second half of the twentieth and early twenty-first centuries and it had created a broad base for operating and reliability characteristics calculations. Functional reliability of information systems has been studied less, and even less studied are general reliability characteristics of a hardware-software complex (HSP), as of the hardware and information utensils interaction results [9, 10].

Briefly we look at the terminology related to the information systems, which today is not but so consistently and generally accepted as the presented above for the technical systems.

Information support. We consider this type of means providing, since research information support for system reliability is essentially the major topic. The definition of "information support" is hard to formalize, because it consists from a large number of dissimilar constituents.

The structure of information support at the systems construction stage contains a variety of components, including:
– physical and mathematical models that homomorphically reflect systems operation at the performance of *n* sequences of the required functions for a given service mode, in time and space, taking into account the requirements of usage;
– basics of calculative and performance parameters and characteristics, including reliability characteristics of technical devices, modules and subsystems, which are used at the systems creation etc.;
– database of testing, measurement, control and diagnosis of an operation, results of its processing etc.;

- algorithmic provisions for the computer simulation software, including calculative simulation computing tasks solving for the created system structure various options etc.;
- algorithmic support for the various subsystems system design:
  - automated design (CAD),
  - statistical data measurement, monitoring and diagnostics,
  - automatic control of operation functional modes,
  - system dialog management type "system-operator" etc.;
- software implementation of mathematical and algorithmic provisions.

Informational support for the reliability studies in this work is considered in a broad sense and at all stages of a system life cycle. Naturally, such a provision is the part of information system software. However, as this part is common, there is no clear topics separation, because the reliability of a system is determined by all without exception its constituent elements, components and modules.

It should be also taken into consideration the dynamics of software integrated information accumulation; its adjustments and changes within the process of new information introduction during the system life cycle development.

Role and content of information provision reflects the general approach to these complex information products, theirs information source. It should be also noted that given for the important role of information provision in research performance, including reliability, it is advisable to name the hardware-software complex (HSC) as hardware-information complex (HIC).

The information signal is a physical carrier of informational content. The results of information signals action form the databases for measurement, control and diagnostic, results treatment, tests protocols, specification and design documents and so on.

The storage media of information content can be electromagnetic, electrical, vibration, acoustic, seismic, and signals of other nature. To describe them are used mathematical models of deterministic and random functions – both one-dimensional and multidimensional.

Large part of the information signals are the time series obtained by time sampling, discretization, quantifying on the levels of continuous (analogous) signals and coded in most cases in binary system. Such signals are referred to as digital.

Object's execution of n required functions sequence is defined by the specific purpose of a system, simultaneously it is defined both with the number of n, and the by the nature of these functions performing.

Reliability enhancement programs include a wide range of measures to improve the system reliability at all stages of its life cycle, during the design and production; at the use of different types of backup; at processing and renewal technology operation phases; at repair; upgrade and maintenance.

1.3. The reliability theory mathematical apparatus

Reliability theory mathematical apparatus is fundamentally represented in the considerable amount of scientific publications [4–6, 9, 10].

Analysis of publications in the field of engineering systems reliability supports the fact, that the reliability theory is the most sophisticated and well-developed area of reliability research foundations. This is natural, due to the fact that the methods used in reliability theory are also applied in other sciences, such as in probability theory, in mathematical statistics, theory of measurement etc. Therefore, the introduction of new research methods into a number of sciences and technologies has been, is and will be the source of parallel methods in the reliability theory.

It is essential to consider also the following points. The technical systems reliability mathematical apparatus incorporates the described below constituencies (components) of the research areas:

- physical and other principles, laws of construction and functioning of specific technical systems, examples of which can be mechanics, electronics, nuclear physics etc.,
- domains of the established systems use, examples of which are transport, energy, space research topics etc.,
- methods of natural sciences and engineering, examples of which are probability theory, mathematical statistics, computational mathematics, metrology (measurement), control theory etc., all as the subjects of general mathematics.

In Figure 1.1 is presented an illustrative diagram of the above mentioned areas of mathematical research interactions.

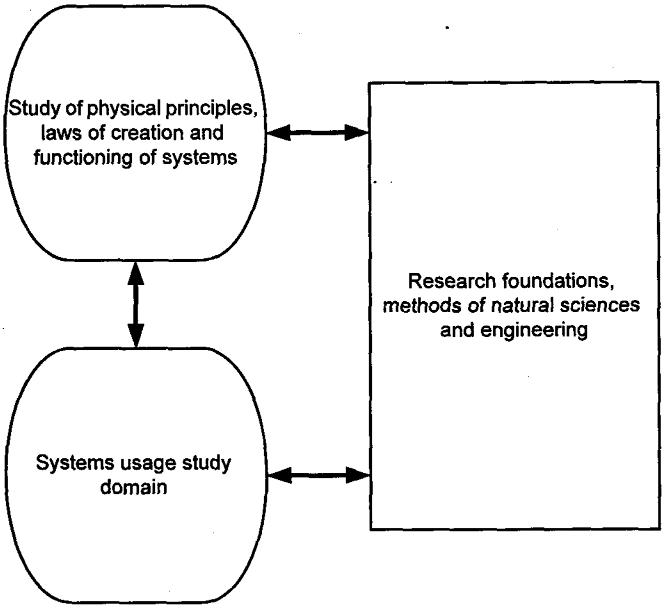

Fig. 1.1. Major areas of technical systems reliability mathematical apparatus research

Naturally, a complete description of technical systems reliability mathematical apparatus inducement deserves a monograph, may be more than one. In our paper are considered only the major research areas of the general mathematical tools, namely the use of scopes of science and technology methods adapted to the life cycle stages of the emerging technical systems.

1.3.1. The reliability theory axioms

Reliability theory widely uses the methods of various fields of science and technology for solving a wide range of different tasks of reliability. At the same time, such diversity of its application for the research of technical systems reliability is questioning the very existence of "reliability" as of an independent science.

It is known that most sciences possess characteristic functions that distinguish, on the one hand, the science specifying among others and on the other, plays an important role in the research areas of that science. Examples can be presented as in:

- chemistry – Periodic Table of chemical elements by D.I. Mendeleev,
- geometry – the axioms (postulates) of Euclid,
- electrodynamics – Maxwell's equations,
- probability theory – axioms by A.M. Kolmogorov,
- propagation of elastic waves in the physical media – "the wave's equation" etc.

It can be cited other examples of such characteristic features for the defining of science.

As for characteristic function in reliability theory it can serve technical systems reliability technical characteristics, but a common methodology of its definition does not exist. The number of reliability characteristics with the growth of technical systems complexity is increasing, for example, recently was published the analysis of measuring devices metrological reliability. The described below system reliability theory axioms is offered as the characteristic element in the technical systems reliability consideration as of a science.

System of reliability theory axioms. Below is presented the variant of the reliability theory axioms system. An important aspect in the formulation of axioms was the issue of what approach to formalize the reliability theory should to be used? At the proposed variant approach it is used a functional definition of reliability (definition provided by the State Standards). On the basis of a large number of research results regarding the objects of reliability obtained at its creation and operation, the mentioned axioms system can be formulated as the following below [10, 11].

Axiom 1. *Facility provides performance of j-st* $(j = \overline{1,n})$ *requisite functions from a given sequence of n required functions in time and space at implementing a specific set of conditions if the changes of values and characteristics of the information signal, which homomorphically reflects the performance of j-st function of that object under different operating modes, are held within the prescribed limits. Analysis of changes in the values and characteristics of the information signal is based on the results of one of the described below options:*

a) performing, calculation, including computer simulation, using a mathematical model of an information signal;

b) processing the real measurement data and control over values and characteristics of the information signal;

c) implementation the options a) and b), as well as the comparative analysis of its results.

Axiom 2. *The object is workable (ensures trouble-free operation) within specified time intervals and spatial area, if the object while is performing a sequence of required functions* *in the specified modes and conditions of use and the performance of each of them satisfies the demands of axiom 1.*

Axiom 3. *Quantitative or normalized measurements of object performance of one, several or all the given sequence of n functions as of the indispensable reliability characteristics is a function of time. Determination of reliability characteristic is based on the results of particular option implementation: a) or b) or c) specified in the axiom 1. The major integral reliability characteristic of an object is the quantitative measure – the duration of the object's fail-free performance (operation) time interval.*

Axiom 4. *The object does not provide the ability to work from some fixed point in time, if at the particular set of object application implementation conditions occurs an event (turmoil) type of the described below:*

d) failure, in narrow sense, at object failure to fulfill, starting from the above mentioned point in time, one from the n set sequences essential functions;

d) refusal, broadly speaking it is considered if an object refuses to perform, starting from the above mentioned point in time, one or more functions from the specified sequence of n required functions.

Determination the time points periods for the object performance failure type d) or e) is made on the results of one of performance variants: a) or b) or c) specified in the axiom 1.

The proposed axioms system is consistent but incomplete:

– consistent, because the real objects – technical systems meet the specified axioms;
– incomplete, as the defined axioms can be used at different life cycle stages of an object, for example, during the designing and operation and as a result to get the divergent results of studies those will be needed to agree.

In addition, at the application of this axioms system it can be generated different versions of tasks for the same object reliability studies.

Concerning the independence of axioms using. it should be noted the following. In axiom 1 are formulated almost all requirements for all supplementary axioms implementation. Therefore, a combination of every axiom 2, 3 or 4 with axiom 1 can be made independently of each other.

1.3.2. Direct and inverse tasks of reliability

For the reliability problem solving is proposed to conduct two-stage analysis of reliability [10, 11]:

– a priori reliability analysis at theoretical, including simulation, studies,
– posteriori reliability analysis for the reliability characteristics practical assessments.

This reliability theory problems classification plays a significant role in the grounding tasks settling, at using varied initial data, at choice of direct mathematical research tools.

We will focus at the reliability problem statements adapted to the life cycle of industrial systems.

There can be offered the described below definitions.

Direct problems of reliability theory – grounding the calculative characteristics of created technical systems reliability during the theoretical and simulation (modulating) studies of reliability.

Thus, at the technical system designing stage, on the basis of a priori database (the knowledge base), according the results of similar systems research, including laboratory and experimental during the process of theoretical studies can be grounded:

- mathematical models,
- algorithms for determining the reliability characteristics, which allows performing the appropriate calculations and developing software for modeling.

In general, a simulation form for a particular system can be carried out on models of different physical nature. These models can be restricted to geometric dimensions, such as the models of airplanes for research in wind tunnels are equivalent to the electrical modeling systems in mechanical systems models. But nowadays most powerful method of mathematical and computer modeling is in using modern computer technology.

The widespread introduction of computer technology, the use of new information technologies has greatly enlarged the possibilities for computer simulation, structures of different options, performance, reliability characteristics. Rationalization of best options using optimality criteria (e.g. minimizing weight, energy and economic performance) enhances the efficiency of technical systems in its respective branches of science and technology.

We offer the described below definition.

Inverse problems of reliability at the system creating stage includes obtaining from the test and operation trial data its statistical treatment results, theirs verifying basing on statistical methods, such as via the use of statistical hypotheses, matching the technical system reliability characteristics with the same design reliability characteristics.

Comparative analysis of direct and inverse problems of reliability methodology allows to reconciling the theoretical and experimental studies of scientific and engineering problems of technical systems reliability tasks solving. The results of this analysis provides in some cases an opportunity to achieve a coordination of the theory and practice, in others – formulate on the basis of inconsistent problems the long-term tasks of theory and practice for the technical systems reliability basics.

For the purpose of the statements and methodology for the direct and inverse problems of reliability solving disclosure in Figure 1.2 is presented a simplified exemplary diagram of the major directions for the direct and inverse problems of the theory of reliability solution results obtaining.

We look in more detail at the technical systems reliability mathematical apparatus. Some more proficient study of the technical systems usage has contributed at the same time to the technical systems reliability mathematical apparatus development, both for the hardware and software systems.

This section will contain only the major lines of the mathematical apparatus of the reliability theory researches, which are adapted to the technical systems life cycle.

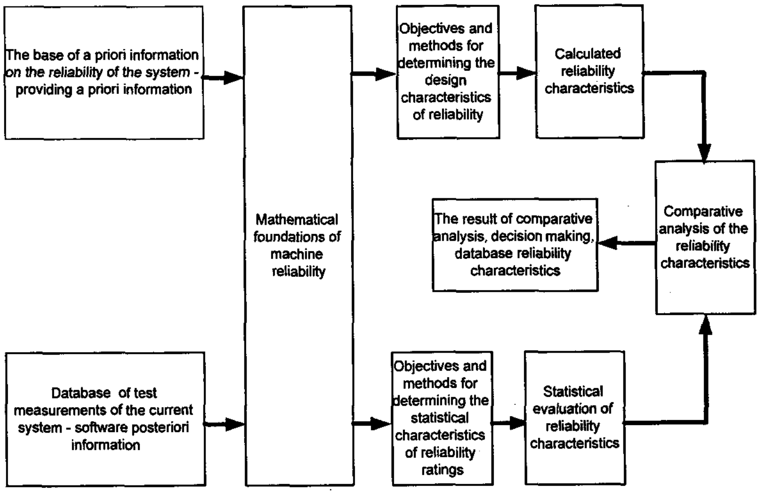

Fig. 1.2. Illustrative diagram for the calculated and statistical reliability characteristics directions determining

In Figure 1.3 is presented a conventional illustrative diagram of an object basic life cycle stages reliability research relationship with the fundamentals and techniques of natural sciences and engineering for two types of reliability characteristics as shown below:

1) calculative (direct problem),
2) experimental (inverse problem).

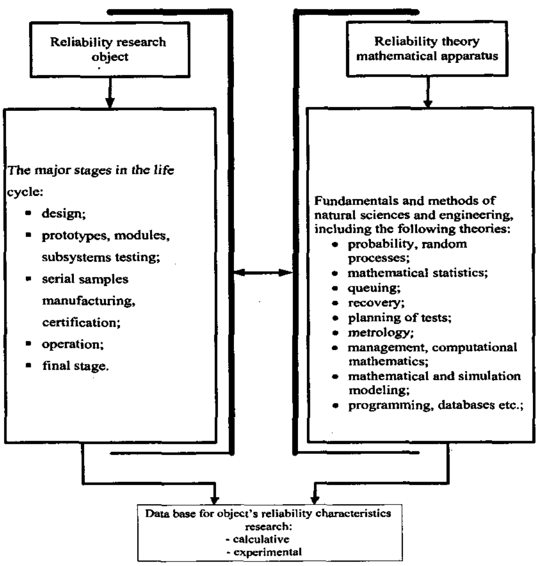

Fig. 1.3. Illustrative diagram of relationship between the objects investigated life cycle stages areas using mathematical apparatus for reliability research

In the subsequent sections are presented, regarding the implementation at the corresponding stages of technical systems life cycle reliability research, the major directions of general mathematical apparatus application.

1.3.3. System design stage

Before the technical system design phase is done, it should be conducted much of work on its study, development and coordination of the posed specification for the system between the client (agency, ministry) and performer – the developer of the system (design office, design or research institutes). In the technical project for the system it should be included every single one of specifications, especially concerning the reliability characteristics, time deadlines for system development, testing, certification, for system transfer into operating and also information about the system development cost.

At the design stage of the system it should be carried out a significant amount of theoretical, simulation and experimental (laboratory) studies on the basis of which will be developed technical and design documentation for the pre-production of sample and serial system items and also completion works on preparation of the production.

At this stage are implemented mostly theoretical and simulation studies in order to obtain reliable design characteristics for the specifically developed technical system. Calculated reliability characteristics are the basis, which is used in subsequent life cycle stages of a particular system and can be adjusted in the succeeding studies, for example at using data of field (experimental) tests of system operation.

Thus the technical systems reliability mathematical apparatus is used completely. At the later stages of the theoretical and simulation (modeling) studies life cycle results obtaining, they may be supplemented by field testing, operational, adjustment, precision data, confirmed by corresponding statistical hypotheses at using approval criteria. Thus, at the drawing phase of such mathematical apparatus usage is created the methodology of theoretical, simulation and experimental studies concerning all stages of system life cycle.

Mathematical models. Mathematical object research model is one of the major components of the above types of reliability guarantee, primarily of informational. Below we formulate the described definitions.

A mathematical model of an object – combination of knowledge, assumptions, hypotheses, requirements, built in the form of coherent logical, seasoned and consistent structures that reflects homomorphically basic properties and characteristics of the research object, relationship, interaction and relationship between its components and modules, written down using mathematical symbols and objects, and designed to solve a particular class of problems.

It is known that the major characteristics (parameters) of the examined object is the result of large number of factors in time and space actions, physical nature of which is stochastic. Therefore, the probabilistic apparatus have found the most widespread use in the creation of reliability theory mathematical models. We consider the following model detailer.

Random variables are probabilistic models, such as the elements uptime term and system renewal time, quantities of wear of mechanical parts at a certain time etc. Note that in determining the reliability characteristics some certain features are compared to the traditional classical setting models of random variables, to the stochastic processes and their distribution laws, which are as following:

- reliability characteristics are the functions of time and comprise physical dimension of time (most of the time unit is 1 hour = 60 minutes = 3600 seconds = $3.6 \cdot 10^9$ micro-seconds = 1/24 = day $\frac{1}{365 \cdot 24}$ of the year),
- in some cases as a unit of object failure rates is used 1Fit = 10^{-9} 1/hour,
- the laws of random variables distribution, namely the probability distribution function $F(t)$ and the probability distribution density $f(t)$ are also functions of time, that is the argument of functions $F(t)$ and $f(t)$ is time, which in most cases has the domain of definition $t \in [0, \infty)$, unlike the traditional argument along the real axis $x \in R = (-\infty, \infty)$,
- as a model of a random variable, in some cases, is used so-called directly given random variable $\xi(\omega)$, $\omega \in \Omega$ for which the domain of definition is the space of elementary events Ω and the ranges of values $\xi(\omega)$ – T coincide with each other, that takes place in the case $\Omega = T$ and for the case $\forall\omega \in \Omega$, $\omega = t$.

We consider the most ordinary laws of probability distribution of probabilistic models – the random variables using within the problems of technical systems reliability.

The limited distribution laws of the independent random variables summation. Physical justification for the use of limit theorems in technical systems reliability problems is based on the described below:

- reliability characteristics of systems are formed at the actions of a large number of factors, which are stochastic in nature, the intensity of each in the total effect is small, and the actions of each of them in space and time are independent,
- each system consists of many elements (this number reaches tens, hundreds, thousands), which are combined with various schemes of connections including serial, parallel and different variants of combinations, so that the operation system is an aggregated set of a large number of existing elements, whilst a significant number of them are operating independently.

The first results on the limit laws were obtained in the classical limit theorems by Swiss scientist J. Bernoulli in the late seventeenth and early eighteenth centuries. Central limit theorem, which is based on the results of the classical limit theorems has defined the class of infinitely divisible distribution laws as the sum of independent random variables and has been proven in the 30 years of the twentieth century by the French scientist P. Levy and Soviet scientists A. Kolmogorov and A. Khinchin.

Here is the general form of the characteristic function $g(u)$, $u \in R$ for the independent random variables distribution infinitely divisible sum law:

$$\eta_n(\omega) = \sum_{i=1}^{n} \xi_i(\omega) \quad \text{when } n \to \infty$$

in the form of Levy:

$$g(u) = \exp\left\{ iau - \frac{\sigma^2 u^2}{2} + \int_{-\infty}^{\infty} \left(e^{iuy} - 1 - \frac{iuy}{1+y^2} \right) dL(y) \right\}, u \in R \qquad (1.1)$$

where: a – the real quantity, $\sigma^2 > 0$ – non negative value, the function L (y) is a no decreasing function on the intervals $(-\infty, 0)$ and $(0, \infty)$, and the integral $\int_{-b}^{b} y^2 dL(y) < \infty$ for any finite b > 0, and from this integration region is excluded zero.

Levi's form (1.1) essentially characterizes infinitely divisible distribution law as the sum of Gaussian and Poisson components. Here the function L(y) characterizes the Poisson component; it is also called the spectral function of Poisson jumps. The value σ describes the Gaussian component. At $\sigma = 0$, $L(y) \neq 0$ we have Poisson component, at $\sigma > 0$, $L(y) \equiv 0$ – Gaussian.

Characteristic function $g(u)$ of infinitely divisible laws along with Levi form can be represented as the corresponding equivalent forms by:

– Levy-Khinchin,
– Kolomohorov (for the case of finite variances).

Below are presented partial cases of limit theorems for the sums of independent random variables that are used in the problems of reliability solving.

Poisson's theorem. If in n independent trials an event A has a low probability p, then for the large values of n the probability $P_n(m)$ of the event appearing A exactly m times will be equal:

$$P_n(m) \approx \frac{\lambda^m}{m!} e^{-\lambda} \quad (m = 0,\ 1,\ 2,\ldots),$$

where $\lambda = pn.$

Integral theorem by de Moiré-Laplace. If in a sequence of independent trials the probability of an event A equals to p, whereas $0 < p < 1$, then the probability that the number μ of occurrences of event A in n successive trials satisfies the inequality (a and b, $b >$ a random numbers)

$$a \leq \frac{\mu - np}{\sqrt{np(1-p)}} \leq b,$$

and at large n is close to

$$\frac{1}{\sqrt{2\pi}} \int_a^b e^{-\frac{z^2}{2}} dz.$$

We consider the typical laws of random variables distribution, which are widely used as a mathematical model for the problems of varying complexity technical systems reliability study and also used at the appropriate stages of their life cycle.

1. Binomial law of a discrete random variable distribution $\xi(\omega)$ type:

$$\mathbf{P}\{\omega \in \Omega : \xi(\omega) = k\} = C_n^k p^k (1-p)^{n-k}, k = 0,1,2,\ldots \qquad (1.2)$$

describes a wide range of experimental results conducted according the so-called Bernoulli scheme. In reliability theory according Bernoulli scheme are used failure tests of various mass production items of technical systems, including elements, links, modules and devices.

In such experiments, the reliability as the random variable $\xi(\omega)$ determines a random number of k failures in n series of tests carried out under the same conditions and independently of each other. The result of each test is the *event A* – failure, which occurs with probability $\mathbf{P}(A) = p$ and to which is attributed number 1 or *event B* – the no failure, which occurs with probability $\mathbf{P}(B) = 1 - p$ and to which is attributed digit 0.

The random variable $\xi(\omega)$ is of two-parameter (n, p) and it has the following first two moments:

$$\mathbf{M}\xi(\omega) = np, \qquad \mathbf{D}\xi(\omega) = np(1 - p).$$

2. Poisson law is a one-parameter discrete value (n, p) distribution law type of:

$$\mathbf{P}\{\omega \in \Omega : \xi(\omega) = k\} = \frac{\lambda^k}{k!} e^{-\lambda}, k = 0, 1, 2, ... \tag{1.3}$$

where the parameter λ characterizes the intensity of an event per time unit. Typically, for the events that have very low probability of occurrence along the time axis in a series of tests $n \to \infty, p \to 0, np \to \lambda$, it takes place (1.2), i.e.:

$$C_n^k p^k (1-p)^{n-k} \sim \frac{\lambda^k}{k!} e^{-\lambda}.$$

Random variable $\xi(\omega)$ has the following first two points

$$\mathbf{M}\xi(\omega) = \mathbf{D}\xi(\omega) = \lambda.$$

In the reliability theory Poisson law is used to describe the flow of random events, such as failures in technical systems, and more.

3. Exponential or exponential law of distribution of a continuous random variable $\xi(\omega)$ with a range of values $(0, \infty)$ is described by the following probability distribution density:

$$f(t) = f(t, \alpha) = \alpha \exp(-\alpha t), \alpha > 0 \tag{1.4}$$

The first two moments of the random variable $\xi(\omega)$ are defined by the expressions:

$$\mathbf{M}\xi(\omega) = 1/\alpha, \qquad \mathbf{D}\xi(\omega) = 1/\alpha^2.$$

In reliability theory, study of such random variable occupies outstanding place. Despite the fact that the model of exponentially distributed random variable is used to study the technical systems reliability, systems which do not change its characteristics and parameters in time and space, do not wear out and are not aging, it is the yet the random variable that allows to get in most cases and at the design phase the primary calculative technical systems reliability characteristics.

4. *Gauss's law or the normal law* of a continuous random variable $\xi(\omega)$ distribution with domain values $(-\infty, \infty)$ is two-parameterical and is described by the following expressions:

– probability distribution density:

$$f(t) = f(t; a, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(t-a)^2}{2\sigma^2}\right) \tag{1.5}$$

– distribution function:

$$F(t) = \mathbf{P}\{\omega \in \Omega : \xi(\omega) < t\} = \int_{-\infty}^{t} f(x)dx = \Phi\left(\frac{t-a}{\sigma}\right) \tag{1.6}$$

where the values of the integral probability:

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} \exp(-z^2/2)dz \tag{1.7}$$

are calculated and can be found in the tables in the scientific publications on the theory of probability and mathematical statistics.

The first two moments of Gaussian random variable are defined as:

$$\mathbf{M}\xi(\omega) = \alpha, \qquad \mathbf{D}\xi(\omega) = \sigma^2.$$

Gauss law belongs to the infinitely division distribution laws, so in a series of tests $n \to \infty$ and $np \to \infty$

$$np \to \infty,$$

where

$$x = \frac{k - np}{\sqrt{np(1-p)}}, \Delta x = \frac{1}{\sqrt{np(1-p)}}, x \in (-\infty, \infty)$$

$$\mathbf{P}\left\{\omega \in \Omega : x_1 \le \frac{\xi(\omega) - np}{\sqrt{np(1-p)}} \le x_2\right\} \sim \frac{1}{\sqrt{2\pi}} \int_{x_1}^{x_2} \exp\left(\frac{z^2}{2}\right)dz.$$

Despite the fact that Gauss law is also of certain degree idealization, its use in the study of technical systems reliability problems is supported by a large number of practical examples.

Gauss law as a base is used for such distribution laws:

- truncated normal,
- log-normal,
- χ^2 distribution,
- Fisher's distribution etc.

5. Gamma distribution of a continuous random variable $\xi(\omega)$ with a range of values $(0, \infty)$ and two parameters (α, λ) has the following distribution density

$$f(t) = f(t;\alpha,\lambda) = \frac{\lambda^{\alpha}}{\Gamma(\alpha)} t^{\alpha-1} \exp(-\lambda t), \tag{1.8}$$

where the $\alpha > 0$, $\lambda > 0$ positive value parameters, α is called shape parameter, and α – distribution scale parameter, and

$$\Gamma(\alpha) = \int_{0}^{\infty} y^{\alpha-1} e^{-y} dy$$

is the gamma function, which at integer $\alpha = n + 1$, $n \in N$ is defined as

$$\Gamma(n) = (n + 1)!, \Gamma(1) = 1.$$

5a. At $\alpha = 1$ the gamma distribution is described by exponential distribution law (1.5).

5b. With an integer number $\alpha = n \in N$ the gamma distribution is described by the Erlanger distribution, i.e.:

$$f(t;n,\lambda) = \frac{\lambda^n}{(n-1)!} t^{n-1} \exp(-\lambda t). \tag{1.9}$$

It should be noted that the use of the gamma distribution law and its particular cases in the majority cases is connected with the technical systems failures characteristics.

6. Weibull distribution of continuous random variable $\xi(\omega)$ with a range of values $(0, \infty)$ and the two parameters (α, λ) has the following distribution density function:

$$f(t) = f(t;\alpha,\lambda) = \alpha\lambda t^{\alpha-1} \exp\left(-\lambda t^{\alpha}\right) \tag{1.10}$$

and therefore:

$$M\xi(\omega) = \frac{\left(1+\frac{1}{\alpha}\right)}{\lambda^{1/\alpha}}, \quad D\xi(\omega) = \frac{\left(1+\frac{2}{\alpha}\right) - {}^2\left(1+\frac{1}{\alpha}\right)}{\lambda^{2/\alpha}}.$$

A significant number of probabilistic models in problems of reliability studies, mostly of mechanical systems, use effectively the Weibull distribution, confirming the real fact, that the appearance and grounding of such distribution study was based on experimental studies of ball bearings reliability.

6a. At the $\alpha = 1$ Weibull law is described by exponential law.

6b. At $\sigma = 2$ the Weibull law is described by the Riley law.

To the laws of distribution which can be provisionally called modern and which are the solutions of stochastic differential equations that describe the physical diffusion processes of degradation – the wear and rupture of engineering systems, belong the following two distributions.

7. DM – diffuse monotonous distribution of so-called random diffusion processes, and which, as a mathematical models, are used in the studies of reliability characteristics of mechanical systems, where mostly dominate failures caused by the processes of wear, fatigue and corrosion are described by:

$$\begin{aligned} f(t) &= f_M(t;\mu,\nu) = \frac{t+\mu}{2\nu t\sqrt{2\pi\mu t}} \exp\left(-\frac{(t-\mu)^2}{2\nu^2\mu t}\right), \\ F(t) &= F_M(t;\mu,\nu) = \Phi\left(\frac{t-\mu}{\nu\sqrt{\mu t}}\right), \\ M\xi(\omega) &= \mu(1+\frac{\nu^2}{2}), \\ D\xi(\omega) &= \mu^2\nu^2(1+\frac{5\nu^2}{4}). \end{aligned} \tag{1.11}$$

8. DN – diffuse non-monotonic distribution models of random processes which are used in studies of the electronic systems reliability which consist of electrical equipment

and mechanical components, the major cause of failures in them are processes of aging and various cases electrical and fatigue processes are described by the following expression:

$$f(t) = f_N(t;\mu,v) = \frac{\sqrt{\mu}}{v t\sqrt{2\pi t}}\exp\left(-\frac{(t-\mu)^2}{2v^2\mu t}\right)$$

$$F(t) = F_N(t;\mu,v) = \Phi\left(\frac{t-\mu}{v\sqrt{\mu t}}\right) + \exp\left(\frac{2}{v^2}\right)\cdot\Phi\left(-\frac{t+\mu}{v\sqrt{\mu t}}\right) \qquad (1.12)$$

$$M\xi(\omega) = \mu$$

$$D\xi(\omega) = \mu^2 v^2$$

In the distribution of 7 (DM-distribution) and 8 (DN-distribution) are used the described below parameters:

– μ is a scale parameter of diffusion distribution laws and its value is inverse to the average degradation rate a, i.e.:

$$\mu = \frac{1}{a},$$

– form parameter in the diffusion distributions laws for the degradation processes is the variation coefficient v, the value of which is determined according the formula:

$$v = \frac{\delta_a}{a},$$

where δ_a – mean square deviation of the degradation process a average rate.

Examples of the random functions (random variables, stochastic processes) with such probability distribution laws that were used as models at the study of technical systems reliability problems are presented in a large number of publications.

Random processes. Efficient use of methods for determining the technical systems reliability characteristics is fully dependent on the adequacy of mathematical models of the examined systems functioning. These models are stochastic processes that are ordered by time sequence of random variables. A large number of factors influencing the operation of technical systems have stochastic physical nature, which justifies the use of random processes. Speaking on the general class of stochastic processes, it can be concluded that for considerable number of technical systems functioning models the problems of their reliability characteristics determining are described by the class of stochastic processes with independent increments and infinitely divisible distribution laws, which are particular cases of distribution laws by Gauss, Poisson, Gamma distributions, etc. The structure of these processes is built with two additive components: Gaussian, which describes a continuous process that accumulate in the systems, such as the aging process, type of various processes of diffusion nature, and Poisson's which characterize pulse (discrete) processes such as rejection, the instantaneous in time disorders of the elements, modules, units and subsystems.

In the class of stochastic processes with independent increments most often are used the described below models:

- Markov and semi-Markov stochastic processes,
- homogeneous and nonhomogeneous Poisson processes,
- renewal process.

Important role in the studies of technical systems reliability characteristics plays the result of the described below problem solution:

- determination of statistical characteristics by crossing trajectories (realizations) the processes of functioning of a given level (area of permissible intensity levels) that characterize denials in the frames of the theory of random processes ejections,
- time moments of characterstics disordering process, parameters of the system operation.

Specifying the type and characteristics of the random process is grounded by the formulation of a particular problem of characteristics solution which determines the examined technical system reliability.

Methods of mathematical statistics. It is known that mathematical statistics is based on the theory of probability, an accurate description and interpretation of which, in its turn, uses the theory of measurement and integration. Mathematical statistics is a branch of mathematics devoted to the mathematical methods of systematization, processing and use of statistic data at the observations of measurements and tests.

In the problems of engineering systems reliability the methods of mathematical statistics are used primarily for the processing of statistical data during the facilities reliability testing.

At the design stage, basing on sound mathematical models of reliability, durability, maintainability and preservation of technical systems there were developed methods of such test data statistical processing.

More specifically, the methods of mathematical statistics will be considered at the appropriate life cycle stages of technical systems.

In the following section we consider one of the important results of mathematical statistics.

The law of large numbers. The major results of the law of large numbers, which occupy a leading position in the theory of probability and mathematical statistics and which is used in reliability theory, is the fact that at testing of various objects on the reliability there will be set out the general conditions at which the tests provide statistical stability of the average reliability characteristics. We consider detailer the law of large numbers.

The law of large numbers in the form by Bernoulli. Suppose that in a sequence of independent test an event A has a constant appearing probability p and the μ means the number of occurrences of event A in n successive tests. Then whatever be a positive digit $\varepsilon > 0$, at $n \to \infty$ there follows:

$$\lim_{n\to\infty} \mathbf{P}\left\{\left|\frac{\mu}{n} - p\right| > \varepsilon\right\} \to 0,$$

where $\mathbf{P}\{\cdot\}$ – the probability of a random event that is written in curly brackets.

In the early twentieth century French mathematician E. Borel have proved that:

$$P\left\{\lim_{n\to\infty}\frac{\mu}{n}=p\right\}=1.$$

Bernoulli and Borel theorems are bases for the probability occurrence estimation of an known A by means of its occurrence frequency, i.e. the value $\frac{\mu}{n}$.

The law of large numbers by Chebyshev. If the sequence of pairwise independent random variables $\xi_1(\omega), \xi_2(\omega),\ldots\xi_n(\omega)$ is such that their mathematical expectation $\mathbf{M}\xi_n(\omega)=a_n$ are [illegible] and variances $\mathbf{D}\xi_n(\omega)=\varepsilon_n^2$ are limited by the same constant $C(\max \mathbf{D}\xi_n(\omega)\le C)$, then at $n\to\infty$ and any kind of positive constant ε:

$$\mathbf{P}\left\{\left|\frac{1}{n}\sum_{k=1}^{n}(\xi_k(\omega)-a_k)\right|\le\varepsilon\right\}\ge 1-\frac{C}{n\varepsilon^2}.$$

from there follows that when $n\to\infty$:

$$\mathbf{P}\left\{\left|\frac{1}{n}\sum_{k=1}^{n}\xi_k(\omega)-\frac{1}{n}\sum_{k=1}^{n}a_k\right|\le\varepsilon\right\}\to 1. \qquad (1.13)$$

Methods of statistical hypotheses testing. Such methods are essential for the statistical characterization of technical systems reliability inverse problems solution validation. In most cases for the formulated statistical hypotheses testing: the case of simple hypotheses when there presents a core H_0 and the alternative H_1 hypothesis; a case of complex hypotheses, when there are more than two hypotheses.

For the case of simple hypotheses are used the described below statistical criteria for decision making:

- by Neyman-Pearson and errors of the first and second type likelihood determining,
- by Bayes, with known priori probabilities for two simple hypotheses H_0 and H_1, and also with the optimal minimizing risk rule for a given matrix of loss at accepting one or another hypothesis,
- sequential Wald criterion, when adopting a suitable statistical hypotheses depends on the volume of variable n in the statistical data submitted for decision making (Wald method is called a sequential method of statistical analysis).

We consider the well-known statistical criteria used in non-parametric statistical estimation of probability distributions of random variables.

In general, the formulation of this problem is related to the inverse problems of reliability theory.

For the study of a random variable $\xi(\omega)$ the given sample volume n:

$$t_1, t_2, \ldots, t_n \qquad (1.14)$$

of independent tests series.

One must confirm the statistical hypothesis H_0 about the selected theoretical distribution law $F(t)$ of value $\xi(\omega)$, basing on a sample (1.14) and using statistical consent criteria for a given level of significance α. As a rule $\alpha \in \{0{,}01; 0{,}02; 0{,}05, 0{,}1\}$.

Normally it is built a histogram for a statistical estimation of probability distribution density $f(t)$. There is recommended at a partition of variations number of the sample (1.14) on the m intervals, to choose them as at least 10, and the average number of sample units n_i in each n_i; therefore ($i = \overline{1, m}$) interval also must be at least 10.

For the confirmation of statistical hypotheses H_0 with a given significance level α, which is formulated as

$$H_0 : F_n(t) = F(t),$$

where $F_n(t)$ – empirical and $F(t)$ – theoretical distribution function, are used the described below typical statistical consent hypothesis.

1. Pearson criterion (criterion χ^2). Statistics species:

$$U = \sum_{i=1}^{m} \frac{(n_i - np_i)^2}{np_i}, pi = F(t_i) - F(t_{i-1}). \tag{1.15}$$

as a function of the sample (1.14) has asymptotic χ^2 distribution with the number of degrees of freedom $k = n - r - 1$, where r – number of parameters of the theoretical distribution $F(t)$. The hypothesis H_0 is confirmed if there executes the following inequality:

$$U < U_t,$$

where U_t – quantile level (1 – α) χ^2 – distribution with $n - r - 1$ degrees of freedom.

Pearson criterion is optimistic, that is in practice, decisions based on its use give more positive than negative answers. Therefore, at the positive response it is advisable to check them with other criteria.

2. Kolomohorov criterion (D-criteriont). Uses the following empirical distribution function of the sample (1.14):

$$F_n(t) = \begin{cases} 0, & t < t_1; \\ k/n, & t_k \le t < t_{k+1}, \quad k = \overline{1,m}; \\ 1, & t \ge t_n \end{cases} \tag{1.16}$$

This criterion is based on the use of the maximum difference between the theoretical and the empirical distribution functions $F(t)$ and $F_n(t)$ i.e.:

$$d_n = \max_t |F(t) - F_n(t)|,$$

In his writings, A. Kolmogorov have shown that the random variable $d_n\sqrt{n}$ has asymptotic distribution:

$$K(\lambda) = \lim_{n \to \infty} \mathbf{P}\{d_n\sqrt{n} < \lambda\} = \sum_{-\infty}^{\infty} (-1)^k \exp(-2k^2\lambda^2), \quad \lambda > 0.$$

The boundaries of the critical region – Kolmogorov allocation quantiles for the equation $p = 1 - \alpha$, are given in Table 1.1 as an example.

Table 1.1
Quantiles by Kolmogorov distribution

α	$\lambda_{1-\alpha}$	α	$\lambda_{1-\alpha}$	α	$\lambda_{1-\alpha}$	α	$\lambda_{1-\alpha}$
0.30	0.975	0.10	1.235	0.02	1.518	0.005	1.731
0.20	1.072	0.05	1.358	0.01	1.628	0.001	1.950

Kolmogorov criterion for its use in practice can be called pessimistic, it means that it can produce rather negative than positive responses values. Thus the D-criterion complements the Pearson criterion. If both criteria give the same response, such response can be used with a high level of probability. If the Pearson test gives a positive answer, and D-test – negative, this should be referred to the third criterion.

3. Mises criterion (criterion ω^2). This criterion uses the empirical distribution function (1.16) and metric type standard deviation:

$$\omega^2 = \int_{-\infty}^{\infty} \left(F(x) - F_n(x)\right)^2 dF(x) \tag{1.17}$$

Mathematical expectation of a random variable ω^2 is

$$\mathbf{M}\omega^2 = \int_{-\infty}^{\infty} \mathbf{M}\left(F(x) - F_n(x)\right)^2 dF(x) = \int_{-\infty}^{\infty} \left(\mathbf{M}F_n(x) - F^2(x)\right) F(x) =$$

$$= \int_{-\infty}^{\infty} \mathbf{D}F_n(x) dF(x) = \frac{1}{n}\int_{-\infty}^{\infty} F(x)\left(1 - F(x)\right) dF(x) = \frac{1}{6n} \tag{1.18}$$

To meet the requirements of the mathematical expectation independence of the sample size, it is required to multiply ω^2 by n. Then the test result value and its mathematical expectation is found according the formulas:

$$u = n\omega^2,\ \mathbf{M}\left(n\omega^2\right) = n\mathbf{M}\omega^2 = \frac{1}{6},$$

Similarly can be found variance ω^2 and $n\omega^2$:

$$\mathbf{D}\omega^2 = \frac{4n-3}{180n^3},\ \mathbf{D}u = \mathbf{D}\left(n\omega^2\right) = \frac{4n-3}{180n}. \tag{1.19}$$

With the increase of n the variance criterion tends asymptotically to a value of 1/45. Even at $n > 40$ it can be figured out that $\mathbf{D}u \approx 1/45$. As an example, quantiles of Mises distribution $\mathbf{D}u \approx 1/45$ for the equation $p = 1 - \alpha$ that are required for critical boundary region assessment are listed in Table 1.2.

Table 1.2
Quantiles of Mises distribution

	$z_{1-\alpha}$	α	$z_{1-\alpha}$	α	$z_{1-\alpha}$	α	$z_{1-\alpha}$
0.30	0.1843	0.10	0.3473	0.03	0.5489	0.01	0.7435
0.20	0.2412	0, 05	0.4614	0.02	0.6198	0.001	1.1679

Mises criterion is neutral and it is able to smooth out some large but unlikely ejections. However, it is difficult at calculate the criterion value.

The methods of renewal theory are basic mathematical apparatus at the problems of technical systems backup solving in order to ensure facility reliability.

At the design stage should be grounded direct tasks of elements, blocks, modules and subsystems for the created technical system reserving and for obtaining estimation data about the elements redundancy. Use of such redundancy data is inherent to the important stages of systems design.

Methods of the theory of planning experiments (studies) at the design stage of a technical system are selected depending on the problem. For example, during process of testing have to be solved theirs described below tasks:

- confirmation of the system functioning,
- compatibility of its modules and subsystems operations,
- verification of computer models that were used at the design,
- evaluation and confirmation the required reliability level characteristics for durability and maintainability of the system.

Also there have to be developed the methods of trials, statistical data testing, coordination the calculated design reliability characteristics with the experimental reliability characteristics.

The methods of queuing theory are used at the.reserving of elements, modules and subsystems during the system design problems formulation. There is a whole class of technical facilities with similar queuing systems.

Methods of theory of measurement (metrology) are used at the subsystems measurement, control and diagnostics construction.

Methods of control theory are used at the created system subsystems controls designing.

Methods of computable mathematics enable to determine the accuracy of the reliability characteristics that has been obtained at computer experiments.

Methods of mathematical and simulation modeling are key items at the design stage of the system. On its basis are created:

- mathematical software;
- software for the corresponding computational experiments, carried out a comparative analysis of the created system structure options.

Methods of programming and databases creating make possible to create digital techniques technical design documents for the system construction and production using computer technologies.

The level of design automatization. Computer aided design is an important factor that affects the reliability of complex technical systems as it allows to solve the following problems: reduce significantly the number of design errors, improve the quality of design and technological documentation, create conditions for a multiple designing and choosing a best variant, to shorten design period, thereby freeing up some time for revision of technical solutions, parameters alignment and testing performing.

Essential in order to improve the quality and technical systems reliability is software developing by CAD systems, as it allows high-tech programming, advanced testing system use and, also, independent and comprehensive software testing conducting before engineering systems in which those software systems will be installed manufacturing.

According to the level of automation there are three classes of CAD systems: low automated (25%), medium automated (25 to 50%), highly automated (over 50%).

An integral part of computer-aided system construction is the system reliability design. Such system uses a computational method for the reliability characteristics calculation, using the database with reference to components reliability.

1.3.4. Stage of production and testing of prototypes, modules and subsystems

At presence of constructional and design documentation for the formulated system there should be conducted the actions described below:

- productions preparation for the prototypes of modules and subsystems manufacturing,
- at the prototypes manufacture stage are conducted operations on components input control, electrical schemes elements and structures control,
- are implemented the developed at the design stage methodologies and plans for testing, for using tools for the examined values obtaining at the study of modules and subsystems prototypes characteristics and parameters,
- implemented developed at the design stage techniques for tests statistical data treatment and studied experimental modules and subsystems reliability characteristics determining,
- according the calculated and experimental reliability characteristics comparative analysis results, have to be made mandatory adjustments to the project design and in the design documentation,
- according the results of comparative analysis at using statistical consent methods are to be made apposite modifications in the estimated reliability characteristics.

In compliance with the results of the investigations are to be carried out adjustments in the project and design documentation in order for the serial batch model development.

1.3.5. Stage of batch sample production, certification and transmission into operation

At this stage of the life cycle are conducted the described below proceedings:

- preparation the production for the corresponding to the specified reliability characteristics serial sample manufacturing,
- at the serial samples manufacturing is implemented method, describing the developed at the design stage various subsystem modules, checking up its operation in order to carry out the predetermined functions,
- checking up the manufactured serial system item in operation, regarding failure-free work, carrying out its certification using the certified metrological measurement, including system reliability characteristics certification.

Quality control and entrance reliability control. Product quality is a combination of product properties that determine its suitability to meet certain demands in accordance to its purpose. The quality is characterized by the absence of defects. The produced items that have no defects are called suitable. A product that has at least one fault is called defective.

Analyzing the concept of “reliability and quality” we may note the following. On the one hand, reliability is a property, although comprehensive, and the quality is a combination of properties. Because of this, reliability is included as part of the quality of the latter, as the property to conduct specified functions identically to the properties required to meet certain demands according to the intended. On the other hand, the definition of quality” does not include time, therefore quality is determined for a fixed time, while the definition of “reliability” has a supplement – “to keep the prescribed limits values of all characteristics within a time period”. In this sense, the term “reliability” is broader than the concept of “quality”.

From that it follows that under term quality is understood the initial state to the products life, and by reliability – stability of the basic quality properties over time. Obviously, a high level of initial quality does not necessarily mean that the product is guaranteed to retain its quality for a given operating time, and therefore it will have high reliability. It is true also that the reliability depends on the initial product quality. It is not enough to ensure that a facility is functional at the initial time. At occurrence in a facility some manifested or implied faults (defects) that can be developed in failure, the characteristics of its reliability are smaller than of the object in which they are found and removed. Therefore, a major role in reliability ensuring plays quality control.

Quality control is the control of quantitative and / or qualitative performance properties of a product. The major type of control is to control the output of the finished object just came from the manufacturer, on the results of which it shall be taken a decision on its suitability for use. At higher demands regarding reliability a consumer can conduct the quality control of most of the items party which were conveyed from the supplier to the user for utilizing in the product manufacture, repair or operation. Depending on the quality demands, the control may be selective or total. If necessary, the quality control can be supplemented by the manufacturing process supervision, the production process control, which includes modes, characteristics and technologic process parameters control.

Quality entrance control can be combined with the input reliability control. As the entrance the reliability control is typically substantially limited in time, at its organization can be applied methods of forced and accelerated testing and also the reliability prognosis based on the use of non-destructive testing methods.

1.3.6. Reliability during operation stage

This stage of the system life cycle is the longest in time and includes the following operations:

- transportation, installation and commissioning the system,
- permanent monitoring of the system functioning at specified modes using subsystems measurement, monitoring, diagnosis, and management,
- creating the system operation measurements database, followed by specifications, options, information signals measurement data statistical processing,
- implementation the methodology that was developed at the design phase, at the creation of long-term monitoring, at determining the projected system reliability performance,

- system repair methods implementation,
- correction of mathematical software and computer modeling of system upgrade options, conducting simulation experiments and forming recommendations for modernization of the current system in order to improve the efficiency of the facility use to enhance corresponding reliability characteristics,
- recommendations implementation for the system modernization.

1.3.7. The final stage of a system life cycle

This stage is of most science-intensive in the technical system life cycle and lies in the implementation of studies at all stages, its systematization and theoretical, using mathematical tools, results of the reliability study for the specific type of technical systems summarizing. Such generalization of reliability research results provide appropriate scientific, technical, information, mathematical and software grounds on order to create new highly advanced technical system.

At this stage, an effort is to be made for the utilization of the system that has exhausted its service life. In some cases, this system may be used for its not intended purposes.

1.4. Major reliability characteristics

At technical systems-objects reliability research conducting, are mainly used various object's mathematical models, that allow to identify particular reliability characteristics.

To the technical systems reliability characteristics belong quantitative reliability characteristics, which are determined by the methods of statistical reliability theory. Applications features of this theory are primarily characterized by mass production facilities research, provided that that the systems were constructed and operated in a statistically homogeneous conditions to which can be applied statistical probability assessment. The examples are engineering products of electrical and electronic industry characterized by the large parties of its production.

Application of statistical reliability theory to the special and small parties of mass-produced objects is limited. This theory can be applied to individual renewable (repaired) objects, in which, in accordance with the specifications and technical documentation, are allowed repeated failures to describe the sequence of which is used the random events flow model. This theory is also used to the unique and smaller mass-produced objects, which in turn are made from products of mass production. In this case, the calculation of the reliability characteristics of the object as of a whole is made according statistical methods of reliability theory by known reliability characteristics of components and elements listed in the suitable directories of reliability.

Methods of statistical reliability theory can help to establish demands for the components reliability and are based on the requirements for the reliability of an object as a whole.

Statistical reliability theory is a part of a more general approach, according which a technical object refusal design assessment is estimated as a result of a physical object both with other objects and the environment interaction.

At the stage of facilities design and construction the reliability characteristics are interpreted as stochastic mathematical models for the created objects probability characteristics. At the stage of experimental research, testing and operation the role of reliability characteristics of objects performs statistical probabilistic assessment of the relevant characteristics.

Reliability characteristics of objects are introduced at certain modes and operating conditions written down in the legal, technical and (or) construction (design) documentation.

Below are given the following reliability characteristics of technical systems objects:

- *reliability* – quantitative characterization of one or more of those properties which together constitute the reliability of an object at its performance according required functional sequences,
- *unitary reliability* – reliability characteristics that describes one of those properties which together constitute the reliability of the object during its operation,
- *comprehensive reliability* – characteristic of reliability that characterizes several properties in it, which together constitute the reliability of an object at its functioning.

Reliability characteristics are classified according the following criteria:

a) according the object reliability properties that are distinguished by the function of:
   - reliability,
   - durability,
   - maintainability,
   - preservation;

b) by the number of object properties that are defined by the reliability characteristics they are distinguished on:
   - single (characterizes one of the reliability properties),
   - complex (characterized simultaneously several reliability properties, such as failure-free and maintainability);

c) on the number of reliability characteristics of objects they are distinguished on:
   - grouping – which can be defined and posing only for a multitude of objects; the reliability of a single item of such object at the same time is not regulated,
   - individual – which establishes the standards of reliability for each item of an object from the total set in question (or for single object),
   - mixed – can act as group or individual;

d) according the source of information for the levels assessing they are distinguished as:
   - calculative,
   - experimental,
   - operational,
   - extrapolated (prognostic);

   there the extrapolated reliability characteristics are reliability characteristics, pointed or interval estimation of which is determined on the basis of calculations, tests, and (or) from operational data extrapolation (prediction) onto another temporal duration of operation and other service conditions;

e) by dimension the reliability characteristics of objects are distinguished according to:
   - operating time to failure,
   - work during definite time interval,
   - dimensionless (including probability of events).

1.4.1. Reliability characteristics of non-renewable objects

As it was noted earlier, the major task in determining the reliability characteristics of objects performs the corresponding mathematical model of the object [1, 5, 8, 9]. In the reliability theory the most objective criterion for the reliability of a complex object is the probability. This is due to the following functions of probability in failure-free operation:

- it enters as a function of time into another, more general characteristics of the object, such as efficiency and cost,
- it characterizes the reliability changes over time,
- it can be obtained by calculation at the design stage of the object, or as a result of its rating in the process of testing.

Probability of failure-free operation R(t) is prospect that for a given operating time a refusal of the object will not happen, that is:

$$R(t) = \mathbf{P}\{\omega \in \Omega : \xi(\omega) > t\},\ \omega \in \Omega,\ t \in [0, \infty) \tag{1.20}$$

where $\mathbf{P}\{\cdot\}$ – the probability of the events specified in brackets, $\xi(\omega)$ – random variable with domain of definition and values, the current time $t \in [0, \infty)$ is the object time to failure, $\omega \in \Omega$ – elementary random object failure event occurrence within $t \in [0, \infty)$, Ω – space (set) of elementary random events. Probability of frailer-free service $R(t)$ is a function of time t and of object time to failure. Function $R(t)$ is considered continuous and differentiated.

Probability of failure-free service is determined at the provision, that in the initial period of time (the start of the time to the failure deduction) the object has been in working state. Denote with t the time or the total object time to failure (hereafter we call t simply time to failure). The emergence of the first refusal is a random event, and time to failure $\xi(\omega)$ from the initial moment of $t = 0$ until the emergence of this event is a random variable. Probability of failure-free service $R(t)$ of the object ranging from 0 to t is determined exclusively by the expression (1.20).

For statistics date on the failures, the probability of the object failure-free operation is determined according the formula:

$$\tilde{R}(t) = \frac{N - n(t)}{N} \tag{1.21}$$

where $\tilde{R}(t)$ – statistical evaluation of the failure-free operation probability, N – the number of objects at the beginning of tests, $n(t)$ – the number of objects that were failed during the tests time period $t \in [0, t]$.

If the ability of an object to conduct specified functions is characterized by a single characteristic $\nu(t)$, then instead of (1.20) we have

$$R(t) = \mathbf{P}\{\nu_1(t') < \nu(t') < \nu_2(t')\};\ t' \in [0, t] \tag{1.22}$$

where $v_1(t)$ and $v_2(t)$ – limited in terms of performance object characteristics values (these values generally are the functions of time).

Similarly, it is introduced failure free service probability in a more general case, when the object's state is characterized by a sequence of characteristics (parameters) with the permissible, in terms of efficiency, values range of these characteristics.

Probability of failure-free service $R(t)$ is associated with the distribution function $F(t)$ and distribution density of operating time to the first failure

$$F(t) = 1 - R(t);\; f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt} \tag{1.23}$$

Along with the concept of "probability" it is often used the term "probability of failure", which is defined as following: it is the probability that an object has a failure at least once at a given operating time t, being but able to work at the preceding time. Failure probability in the interval from 0 to t is defined according the formula

$$F(t) = 1 - R(t) \tag{1.24}$$

Probability of failure-free service $R(t)$ and the failure probability $F(t)$ are equal to the area under the curve of distribution density function $f(t)$ in the interval $[0, t_1]$ that graphically is illustrated in Figure 1.4.

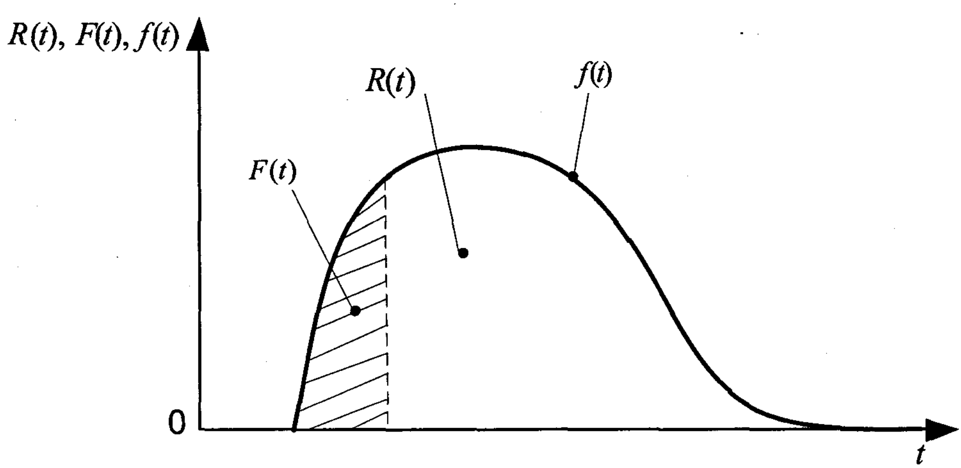

Fig. 1.4. Graphical interpretation of the failure-free operation probability and failure probability

With the increasing of failure-free service of a non-renewable object operating, $R(t)$ decreases monotonically from 1 at $t = 0$, asymptotically approaching to 0 at $t \to \infty$, and the failure probability $F(t)$ increases accordingly, from 0 to 1 (Fig. 1.5).

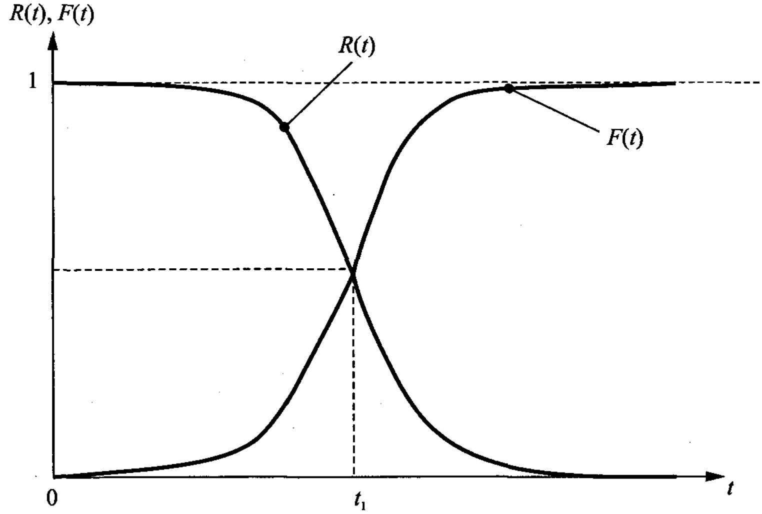

Fig. 1.5. Graph of the probability of failure-free operation and the failure probability during the operating time of object

Probability an item's failure-free servicing till time to failure during the period of $(t, t + \Delta t)$ is the provisional probability that the object is in working state within this operating interval time, determined by the requirement, that the facility had retained the performance until moment t from the beginning of this interval:

$$R(t, t+\Delta t) = \mathbf{P}\{\xi(\omega) \geq t + \Delta t \mid \xi(\omega) \geq t\} = \frac{\mathbf{P}(AB)}{\mathbf{P}(B)}. \tag{1.25}$$

where $\mathbf{P}(B)$ – the probability of the event B occurrence to be in the operability of the object within operating time interval $(0, t)$ (Fig. 1.6); $\mathbf{P}(A|B)$ – the conditional probability of an event A, to be in the object operational state in the interval $(t, t + \Delta t)$, that is determined by the condition of the realization of event B; $\mathbf{P}(AB) = \mathbf{P}(A \bigcup B)$ – the probability of uniting of random events A and B, i.e. the probability of object operability in the interval $(0, t + \Delta t)$.

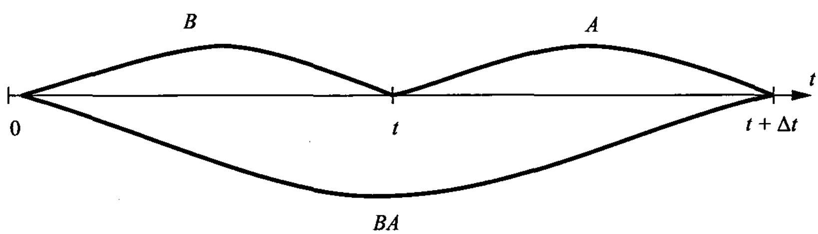

Fig. 1.6. Graphic illustration of events A and B probability to be presenting in the object performance within the operating time in the interval $(0, t + \Delta t)$

Pointed statistical estimations for the probability of failure-free operation $\overline{R}(t)$ from 0 to t for the operating time to failure $\overline{F}(t)$ distribution function are given by:

$$\tilde{R}(t) = 1 - \frac{n(t)}{N},\ \tilde{F}(t) = \frac{n(t)}{N} \quad (1.26)$$

where N – the number of the able to work facilities at the initial time, $n(t)$ – the number of objects that were failed during interval from 0 to t.

To obtain reliable estimations the sample size N should be large enough.

Definition of uptime in accordance with formulas (1.21) and (1.23) is related to the objects that encompass to function for some finite period of time. For real-time (discrete) using of uptime probability is defined as the probability that during the object operation, a rejection does not occur. Similarly, we introduce probability of failure-free switch-in.

Mean time to failure $\mathbf{M}\tilde{R}(t)$ *– mathematical expectation of operating time until to the first failure.*

Mean time to failure is rather an illustrative reliability characteristic. However, the application of this criterion in order to assess the reliability of a complex object is limited to cases when:

- the object operation time is much smaller than the average uptime,
- distribution law of uptime is non monoparametric enough and for a full assessment it requires determination of higher order moments,
- there used reservation,
- operation time of the particular modules and the parts of a complex object are different.

Mean time to failure T_0 is calculated according the formula:

$$T_0 = \int_0^{\infty} t f(t)\, dt \quad (1.27)$$

where $f(t)$ – density function of operating time to failure.

Using (1.23), T_0 is expressed in terms of uptime probability:

$$T \quad \int^{\infty} t dR(t). \quad (1.28)$$

Statistical evaluation for the average operating time to failure is determined according the formula:

$$\tilde{T}_0 = \frac{1}{n} \sum_{j=1}^{N} \tau_j \quad (1.29)$$

Equation (1.29) corresponds to the test plan, under which all N objects are tested till the first refusal.

Thus, the average time to failure T_0 is defined as the mathematically expected value of a random variable $T(\omega)$, $\omega \in \Omega$:

$$T_0 = \mathbf{M}T(\omega) = \int_0^{\infty} t f(t)\, dt. \quad (1.30)$$

Integrating the (1.30) by parts and using objects for which $R(0) = 1$, $F(0) = 0$, $R(\infty) = 0$, $F(\infty) = 1$, that is for the systems that are workable at the initial time $t = 0$ and also that the period of operation time for these systems is finite, we obtain:

$$T_0 = -tR(t)\Big|_0^\infty + \int_0^\infty R(t)\,dt = \int_0^\infty R(t)\,dt. \qquad (1.31)$$

For example, at $\lambda = \text{const}$

$$R(t) = e^{-\lambda t}. \qquad (1.32)$$

Then

$$T_0 = \int_0^\infty e^{-\lambda t}\,dt = \frac{1}{\lambda}. \qquad (1.33)$$

In this case, the reliability function has form $R(t) = e^{-\frac{t}{T_0}}$.

At deriving formula (1.30) it is assumed that the system operates during time t which varies from 0 to infinity. Much of the technical systems have a specified finite service life T_P for such systems T_0 should be determined according the formula:

$$T_0 = \int_0^{T_P} tf(t)\,dt + \int_{T_P}^\infty tf(t)\,dt. \qquad (1.34)$$

The second approach considers that when a system will outsource its technical resource, it is removed from service.

At $t \to \infty$ are $R(\infty) = 0$, so finely:

$$T_0 = \int_0^{T_P} R(t)\,dt \qquad (1.35)$$

Below is the definition of the following reliability characteristics:

Failure frequency is the ratio of number of object failures per time unit to the initial number of the tested objects, provided that all the failed items are not to be restored.

By definition:

$$\tilde{\alpha}(t) = \frac{n(\Delta t)}{N\Delta t} \qquad (1.36)$$

where $n(\Delta t)$ – the number of objects that were failed in the time interval from $t - \frac{\Delta t}{2}$ to $t + \frac{\Delta t}{2}$.

Failure rate is the probability density (or distribution law) of a facility working till the first refusal. Therefore

$$\alpha(t) = R'(t) = F'(t), \quad F(t) = \int_0^t \alpha(t)\,dt.$$

$$R(t) = 1 - \int_0^t \alpha(t)\,dt \qquad (1.37)$$

The next reliability characteristics – failure rate $\lambda(t)$ is mainly used in the analysis of renewable projects. For non-renewable facilities such characteristic is used as the relevant reliability characteristic till the first refusal. In practice, the failure rate $\lambda(t)$ is used for testing the reliability of non-renewable objects of mass production.

Failure intensity $\lambda(t)$ – conditional density of failure probability of the object which is determined according the condition that to definite moment there was no failure.

By this definition we have:

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{F(\Delta t \mid t)}{\Delta t} = \lim_{\Delta t \to 0} \frac{1 - R(\Delta t \mid t)}{\Delta t} \tag{1.38}$$

where $F(\Delta t \mid t)$ – the conditional failure probability of the object in the interval Δt defined at a provision that at the time t the object is in working state; $R(\Delta t \mid t)$ – corresponded conditional failure-free operation probability.

Statistical definitions of test failure rate are defined as:

$$\tilde{\lambda}(t) = \frac{n(t)}{N_{cp} \Delta t} \tag{1.39}$$

where $N_{cp} = \frac{N_i + N_{i+1}}{2}$ – the average number of serviceable objects within the time interval Δt, N_i – the number of serviceable objects at the beginning of the interval Δt; $N_i + 1$ – the number of serviceable objects at the end of the interval Δt; $n(t)$ – the number of objects that rejected at the time interval Δt.

Probability of this characteristic evaluation is found according expression:

$$\lambda(t) = \frac{\alpha(t)}{R(t)} \tag{1.40}$$

Conditional probability according to the definition of conditional probability is written in the form:

$$R(\Delta t \mid t) = \frac{R(t + \Delta t)}{R(t)} \tag{1.41}$$

Substituting the (1.41) into (1.40) we obtain:

$$\lambda(t) = \lim_{\Delta t \to t} \left[\frac{1 - \frac{R(t + \Delta t)}{R(t)}}{\Delta t} \right] = -\frac{1}{R(t)} \lim_{\Delta t \to 0} \left[\frac{R(t + \Delta t) - R(t)}{\Delta t} \right] =$$

$$= -\frac{1}{R(t)} \frac{dR(t)}{dt} = \frac{f(t)}{R(t)} = -\frac{d}{dt} [\ln R(t)].$$

We consider the last equation:

$$\lambda(t) = -\frac{d}{dt} [\ln R(t)] \tag{1.42}$$

Multiplying both sides of (1.42) on dt and integrating in the boundaries from dt to t, we obtain:

$$-\int_0^t \lambda(t)dt = \int_0^t d\left[\ln R(t)\right] = \ln R(t)\,|_0^t = \ln R(t) - \ln R(0) = \ln R(t) \qquad (1.43)$$

Potentiating last equation, we obtain the formula called *the basic formula of reliability*:

$$R(t) = e^{-\int_0^t \lambda(t)dt} \qquad (1.44)$$

In case when $\lambda(t) \equiv 1$ = const, the basic formula of reliability (1.44) represents the exponential distribution law, which is widely used for the modeling of random failures:

$$R(t) = \lambda e^{-\lambda t};\ F(t) = 1 - R(t) = 1 - e^{-\lambda t};\ f(t) = \lambda e^{-\lambda t};\ T_0 = \frac{1}{\lambda}. \qquad (1.45)$$

The typical failure rate curve (failures flow parameter) for the object's operating time is shown in Figure 1.7.

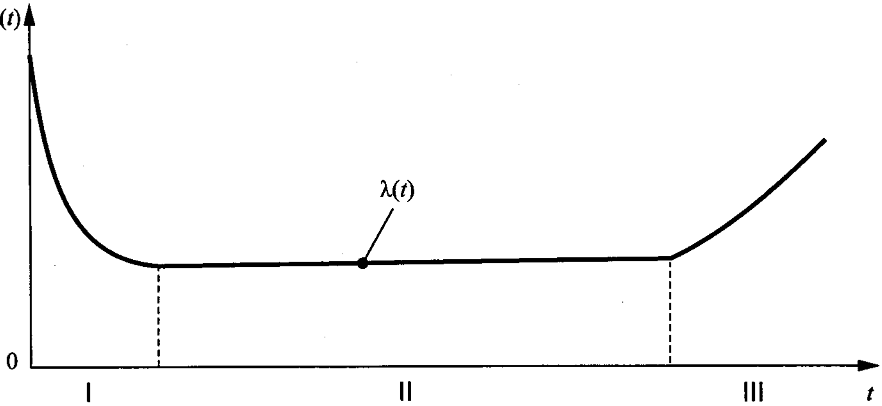

Fig. 1.7. Dependence of failure rate $\lambda(t)$ from the object time to failure

On this curve there are three characteristic areas:

1. *The initial period of operation (during debugging).* Elevated failure rate in this section is due to the presence of hidden manufacturing defects (bad soldering, mounting defects etc.) that appear at the initial period of operation and lead to failure of object.

2. *During normal operation.* During this period, when the rate of accumulation of damages from wear, is yet not as high as the usual failure rate, it has generally low and stable value, the level of which is determined by the function of the object type, its original quality mode and operating conditions. At this period of operation it is observed an action of the specific for the object types of sudden failures, which together determine the level of failure rate in this area.

3. *The final period of operation (degradation time).* **During this period** of operation proceeds the progressive deterioration of the output parameters of the object caused by the accumulation of wear and degradation damages that generate a monotonic increase of failure rate.

Despite the non-linearity of the failure rate curve vs. object time to failure during time intervals on the first and third dependence area in Figure 1.7, in some cases, in practice, at calculating will be chosen $\lambda(t) \equiv 1 = \text{const}$. A prerequisite for this is, firstly, a small time of the installation (running-in) of electronic components and the possibility of eliminating them altogether while the production improving, quality control and culling of the finished product, and, secondly, a significant duration of normal operation. Because of this the unreliable elements which are defected are selected by incoming inspection and discarded, and the elements that remained have small and constant failure rate. Degradation period (downgrading) is excluded from consideration because for the electronic components it comes yet after a long period of normal operation, when electronic systems become morally obsolete and may be written off. If yet the failure rate curve vs. object time to failure is not typical and does not have significant in duration normal operation period, there is a need for approximation of unreliability elements functioning using one of theoretical distribution laws for uptime.

1.4.2. Reliability characteristics of renewable facilities

Reliability models for renewable objects on contrary to non-renewable are characterized only by a reliability model and include three components: a reliability model, renewal model and model of operation control.

For renovated facility timeslot of operation consists of uptime intervals sequence, time intervals for renewal ant time intervals to detect latent failures. Briefly we consider these models.

Failure-free operation models

Such model of renewable facility differs from the non-renewable object only that it is a summation of reliability models between successive failures. Generally are considered cases where the time to failure intervals of renewable facilities are located in the same order in which it follow one by one next failures. This allows investigating the reliability model of renewable objects using the results of studies of random processes describing the sequence of failures. Such processes are referred to, as the streams of random events – failures flows. In the theory of randomness in this case the rejection events are considered as failures flows with the described below characteristics.

1. The number of failures $N(t)$ along the time interval $(0, t)$ and, consequently, $N(\tau, \tau + t) = N(\tau, t)$ in the interval $(\tau, \tau + t)$ when the interval of time countdown is taken from the moment $\tau > 0$ on the time axis $\tau \in [0, \infty)$.

2. Probability of exactly n failures appearing at operating time interval t:

$$R_n(t) = \mathbf{P}(N(t) = n; \quad R_n(\tau, \tau = t) = \mathbf{P}(N(\tau, t) = n). \tag{1.46}$$

3. The probability that in anticipation of time to failure t there emerge at least n failures:

$$\pi_n(t) = \mathbf{P}(N(t) > n) = \sum_{i=1}^{\infty} R_i(t); \pi_n(\tau,t) = \mathbf{P}(N(\tau,t) > n) = \sum_{i=1}^{\infty} R_i(\tau,t). \tag{1.47}$$

4. The average number of failures until the given interval of operating time, which is called a leading function of failures flows:

$$\Lambda(t) = \mathrm{M}N(t) = \sum_{n=1}^{\infty} nR_n(t) = \sum_{n=1}^{\infty} \pi_n(t);$$
$$\Lambda(\tau,t) = \mathrm{M}N(\tau,t) = \sum_{n=1}^{\infty} nR_n(\tau,t) = \sum_{n=1}^{\infty} \pi_n(\tau,t) = \Lambda(\tau+t) - \Lambda(\tau) \quad (1.48)$$

5. The intensity of flow of failures:

$$v(t) = \lim_{\Delta t\to 0} \sum_{n=1}^{\infty} n\frac{R_n(t,\Delta t)}{\Delta t} = \lim_{\Delta t\to 0} \frac{\Lambda(t,\Delta t)}{\Delta t} = \frac{d\Lambda(t)}{dt}$$
$$v(\tau,t) = \lim_{\Delta t\to 0} \sum_{n=1}^{\infty} n\frac{R_n(\tau+t,\Delta t)}{\Delta t} = \lim_{\Delta t\to 0} \frac{\Lambda(\tau+t,\Delta t)}{\Delta t} = \frac{d\Lambda(\tau+t)}{dt} = v(\tau+t) \quad (1.49)$$

6. Failure flow parameter:

$$\lambda(t) = \lim_{\Delta t\to 0} \sum_{n=1}^{\infty} \frac{R_n(t,\Delta t)}{\Delta t} = \lim_{\Delta t\to 0} \frac{\pi_1(t,\Delta t)}{\Delta t} = \frac{d\pi_1(t,x)}{dx}\Big|_{x=0}$$
$$\lambda(\tau,t) = \lim_{\Delta t\to 0} \sum_{n=1}^{\infty} \frac{R_n(\tau+t,\Delta t)}{\Delta t} = \lim_{\Delta t\to 0} \frac{\pi_1(\tau+t,\Delta t)}{\Delta t} = \frac{d\pi_1(\tau+t,x)}{dx}\Big|_{t=0} = \lambda(\tau+t) \quad (1.50)$$

7. The variance of the number of failures until the given time to failure t:

$$\mathrm{D}N(t) = \sum_{n=1}^{\infty} n^2 R_n(t) - \Lambda^2(t);\ \mathrm{D}N(\tau,t) = \sum_{n=1}^{\infty} n^2 R_n(\tau,t) - \mathrm{A}^2(\tau,t) \quad (1.51)$$

8. The distribution function for the object's time to failure interval until the n-st failure:

$$F_n(t) = \mathbf{P}\{\omega \in \Omega : T_n(\omega) < t\} \quad (1.52)$$

At studies of renewable facilities in each particular case are used the corresponding failures flows.

Models of renewal – process of facility rehabilitating consists of following operations:

- failure detection, which is held either by an operator or by automated operation control system,
- localization and diagnosis of rejection, the decision to repair or replace the corresponding element of the module, which were failed,
- working over the facility rehabilitation,
- adjustment of functioning and transfer into subsequent service.

Performing the indicated operations is conducted at corresponding intervals of time, the value of which is described by a random variable $T_j(\omega)$, $j = \overline{1,4}$, $\omega_j \in \Omega_j$.

The total value of a facility rehabilitation time

$$T_{\hat{a}}(\omega) = \sum_{j=1}^{4} T_j(\omega_j) \quad (1.53)$$

is also a random variable.

Distribution law of values $T_{\hat{a}}(\omega)$ in each case is justified with a corresponding model, based on:

- elemental composition, construction of the facility,
- the nature of an element failure,
- requirements for maintenance and repair.

For example, if from all the components (1.53) the basic is time interval of failure liquidation, then it is recommended to use the exponential distribution law with the random variable $T_{\hat{a}}(\omega)$:

$$F_{\hat{a}}(t) = 1 - \exp(-\mu/\overline{T}_{\hat{a}}) \tag{1.54}$$

where μ – the intensity of renewal $\overline{T}_{\hat{a}}$ – the average renewal time.

Subjected to equal intensity of all object's components renewal it is recommended to use the regular distribution law $T_{\hat{a}}(\omega)$:

$$F_{\hat{a}}(t) = \begin{cases} 0, t \le a \\ (t-a)(b-a),\ a \le t \le b \\ 1, t \ge b \end{cases} \tag{1.55}$$

Provided that two or more components are major contributors into (1.53) and they obey to exponential distribution law with parameter μ and other components are small, then the renewal time is described by the Erlang law with parameters k and μ:

$$F_{\hat{a}}(t) = 1 - \sum_{i=0}^{k-1} \frac{(\mu t)^i}{i!} e^{-\mu t} \tag{1.56}$$

where μ – the intensity of the major component renewal with exponential distribution law and k – the number of components.

Renewal models at research can be justified for each element, links, group of links, module and for all object's elements.

Operation control models. Control and diagnostics system for a renewed facility at failures determining processes in two modes:

- at realization of failure as of a random event, the system detects, isolates and diagnoses failure during the facility rehabilitation,
- in the mode of functioning, the system makes it possible to identify hidden failures and in some cases to stop its realization.

On the one hand control and diagnostics makes it possible to increase the reliability of an object, but on the other, for the organization and conducting of monitoring and diagnostics it must be spent quite a few of resources, including hardware, software, all of which increase the risk of researched object basic hardware and software parts failure. Structure and characteristics of control and diagnostics selection and optimization can be made at the examined object complex reliability models study.

To estimate the costs on the hardware monitoring and diagnostics organization at the works on the reliability it is offered a number of models, including logarithmic and logarithmic power.

According to the log-normal model, the coefficient of comprehensiveness control $\beta \in (0,1)$ is associated with the coefficient of relative costs on the equipment control system:

$$\delta = \lambda_k/\lambda_0 \tag{1.57}$$

by the following equation:

$$\delta = \lambda_k/\lambda_0, \tag{1.58}$$

where λ_k and λ_0 – failure rates of controlled and basic equipment, and the parameter $\alpha \in (5,10)$ is determined by the structure and characteristics of the object.

This model is consistent with experimental data at $\beta < 0,98$.

The power model is given by:

$$\delta = \beta^m;\ \beta = \delta^{1/m},\ m >> 1 \tag{1.59}$$

Such model is consistent with experimental data at $\beta > 0,98$.

1. E – exponential distribution with parameters:

$$f(t) = \lambda e^{-\lambda t};\ R(t) = e^{-\lambda t};\ \lambda(t) = \lambda;\ T_0 = \lambda^{-1} \tag{1.60}$$

for systems that does not grow old and do not wear out. Since practically, the systems that do not grow old, do not exist, a number of standards for reliability recommend using the E-distribution only for comparative assessments of reliability.

2. DM – it is diffuse monotonous distribution for systems, for example for the mechanical, where dominate failures caused by the processes of wear, fatigue and corrosion is described by (1.11) i.e.:

$$f(t) = \frac{t+\mu}{2\nu t\sqrt{2\pi\mu t}}\exp\left(-\frac{(t-\mu)^2}{2\nu^2\mu t}\right) \tag{1.61}$$

$$R(t) = 1 - \int_0^t f(x)dx = 1 - \int_0^t \frac{x+\mu}{2\nu x\sqrt{2\pi\mu x}} e^{-\frac{(x-\mu)^2}{2\nu^2\mu}} dx,\ T_0 = \tau\left(1+\frac{\nu^2}{2}\right) \tag{1.62}$$

where μ and $\nu > 0$ – scale and shape parameters. Function $R(t)$ for DM – distribution can be transformed by replacing the variable $\frac{x-\mu}{\nu\sqrt{\mu x}} = u$. Then for $du = \frac{x+\mu}{2\nu x\sqrt{\mu x}}dx$ and to the border changes of x from 0 to t correspond the u changes limits from $-\infty$ to $\frac{t-\mu}{\nu\sqrt{\mu t}}$ therefore:

$$R(t) = 1 - \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\frac{t-\mu}{\nu\sqrt{\varpi t}}} e^{-\frac{u^2}{2}} du = 1 - \Phi\left(\frac{t-\mu}{\nu\sqrt{\mu t}}\right) \tag{1.63}$$

where $\Phi(x) = \int_{-\infty}^{x} e^{-\frac{u^2}{2}} du$ – the probability integral.

3. DN – diffusion for non-monotonic distribution for the electronic circuits and systems, which consist of electrical equipment and mechanical components, the major cause of failures

in which are the processes of aging and various processes of electrical nature and the progression of fatigue is described by (1.12), i.e.

$$f(t)=\frac{\sqrt{\mu}}{\nu t\sqrt{2\pi t}}e^{-\frac{(t-\nu)^2}{2\nu^2\mu t}},\quad R(t)=\Phi\left(\frac{\mu-t}{\nu\sqrt{\mu t}}\right)-e^{2\nu^{-2}}\Phi\left(-\frac{\mu+t}{\nu\sqrt{\mu t}}\right),\quad T_0=\mu. \tag{1.64}$$

4. LN – lognormal distribution for the system where the major cause of failures is fatigue, caused by periodic loads:

$$f(t)=\frac{1}{\nu t\sqrt{2\pi}}e^{-\frac{(\ln t-\ln\mu)^2}{2\nu^2}},\ R(t)=\Phi\left(\frac{\ln\mu-\ln t}{\nu}\right),\ T_0=\mu e^{\frac{\nu^2}{2}}. \tag{1.65}$$

5. W – Weibull distribution is used for systems where reliability is not accurately enough described by distributions E, DM, DN and LN:

$$f(t)=\frac{\nu}{\mu}\left(\frac{t}{\mu}\right)^{\nu-1}e^{-\left(\frac{t}{\mu}\right)^{\nu}},\ R(t)=e^{-\left(\frac{t}{\mu}\right)^{\nu}},\ \lambda(t)=\frac{\nu}{\mu}\left(\frac{t}{\mu}\right)^{\nu-1},$$
$$T_0=\mu\Gamma\left(1+\frac{1}{\nu}\right), \tag{1.66}$$

where $\Gamma(x)=\int_0^{\infty}u^{x-1}e^{-u}du$ is the gamma function for $x>0$.

The considered five divisions of uptime reliability characterize the elements in which λ eventually decreases, remains constant or increases (monotonically or with maximum). The composition of the three distributions Weibull (KW):

$$R(t)=e^{-\left(\frac{t}{\mu_1}\right)^{\nu_1}-\lambda t-\left(\frac{t}{\mu_2}\right)^{\nu_2}} \tag{1.67}$$

(here exponential distribution with parameter λ is a special case of distribution Weibull) can describe the reliability elements that have all three stages of "life cycle" (Fig. 1.4), the initial period of operation ($\nu_1=\nu_2=1$), period during normal operation ($\nu_1=\nu_2=1$) and the final period of operation ($\nu_2>1$).

If the facility failure occurs in case of failure of one of its elements, it is noted, that this object has a serial connection elements. At calculating of such object it is believed that the failure of every element is random and independent event.

Subsequently the probability of the object runtime over time t equals to the probability factors of its uptime elements during the same period. Since the probability of elements over time t can be expressed in terms of failure rate in the form (1.66), then the formula for the failure probability of the object with a series connection of the elements can be written as following:

$$R_c(t)=p_1(t)p_2(t)\dots p_N(t)=\prod_{i=1}^{N}p_i(t),$$
$$R_c(t)=\exp\left(-\int_0^t\lambda_1(t)dt\right)\exp\left(-\int_0^t\lambda_2(t)dt\right)\dots$$
$$\dots\exp\left(-\int_0^t\lambda_N(t)dt\right)=\exp\left(-\sum_{i=1}^{N}\int_0^t\lambda_i(t)dt\right) \tag{1.68}$$

The expression (1.68) is most common. It allows for determining the object flawless operation probability till first failure at any failure rate change vs. time law.

In practice, the most typical object's failure rates are of constant value. Wherein, the time to the failure is described by an exponential distribution law, i.e., for the normal period of equipment work is fair the condition $\lambda = \text{const}$.

In this case, the expressions for quantitative characteristics take form:

$$R_c(t) = e^{-\lambda_c t} = e^{-\frac{t}{\tilde{t}_c}},\ \lambda_c = \sum_{i=1}^{N} \lambda_i,\ a_c(t) = \lambda_c e^{-\lambda_c t},\ \tilde{t}_c = \frac{1}{\lambda_c} \qquad (1.69)$$

If all elements of this type are equally reliable, the failure rate of the system will be:

$$\tilde{t}_c = \frac{1}{\lambda_c} \qquad (1.70)$$

where N_i – the number of elements of i-st type and r – number of item types.

In practice, very often it has to be calculated the probabilities of highly reliable systems, wherein the multiplier $\lambda_c t$ is much less than one, and correspondently the probability $R(t)$ is close to one. In this case, expanding $e^{-\lambda_c t}$ into a series and limiting its first two members, it is possible to calculate $R(t)$ with high accuracy.

Then the major quantitative reliability characteristics can be calculated with a sufficient for practice accuracy, according the following approximate formula:

$$R_c(t) = 1 - t\sum_{i=1}^{r} N_i\lambda_i = 1 - \lambda_c t,\ \lambda_c = \sum_{i=1}^{r} N_i\lambda_i,\ t_c = \frac{1}{\sum_{i=1}^{r} N_i\lambda_i} = \frac{1}{\lambda_c},$$

$$a(t) \approx \lambda_c(1 - \lambda_c t).$$

Calculation of reliability quantitative characteristics according approximate formulas does not give large errors for the systems, failure free operation probability for which is greater than 0.9.

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2. The information system as an object of reliability research

This section contains material that describes characteristics and operation of the information systems. The tasks of projection, collection, transmission, processing, preservation, protection (safety) of various purposes information is the major objective of information systems. Today information systems are used in various societes and industries both as independent objects and subsystems. Detalier here presented an analysis of the systems information security items.

In this book is considered the classification of information signals used for forming, transmission and processing of information, which in conjunction with the hardware of information systems implement in each case information resources.

Also here are considered materials on computer simulation at modeling of random signals realizations based on the use of Monte Carlo method in order to perform an appropriate computer simulation experiments during the studies of information systems reliability [1–8].

2.1. General information about information systems

In the information systems, the focus of research is information of diverse types of its action.

Information. Information is one of the key concepts for many scientific disciplines and society items. Various natural physical processes, relationships in the communities are closely related to information.

A well-known scientist in the field of computer science V.M. Glushkov had stated: "Information in its broadest sense is a measure of the heterogeneity in the distribution of matter and energy in space and time, a measure of changes that accompany all processes in the world (...) information is carried not only by a filled in with the letters pages of a book or by sounds of human speech, but it is also in sunlight, crests of mountains, in the splash of the waterfall, in rustling of tree leaves etc."

Information as a knowledge about the world, eliminating uncertainty it is the subject of information theory research; in philosophy it is a reflection of huge diversity of processes and objects.

The information in the various fields of science and technology is used both as a concept and a term. Information, as a concept, has a deeper meaning and to date does not exist its clear and formalized general definition. But in each case, i.e. adapted to the basics of information systems reliability, the definition of information can be resulted as following.

Information – is knowledge about the properties, characteristics, parameters of the studied phenomena and objects evolving in Time and Space, its relationships between each other.

Information in broader sense reflects the natural and social relationships, and in narrow sense – elements of different fields of knowledge (scientific theories of signals and systems processing, information management, measurement, coding, transmission, digital signal processing etc.).

It has to be classified types of information starting from certain objective functions. In terms of engineering, especially of information systems, important role plays the following version of information classification that is illustrated in Figure 2.1.

This classification of information plays a major role in grounding of ***n*** functions implementation required by the information systems in order to ensure the reliability of its operation. Further, such set of n functions will be required to be specified.

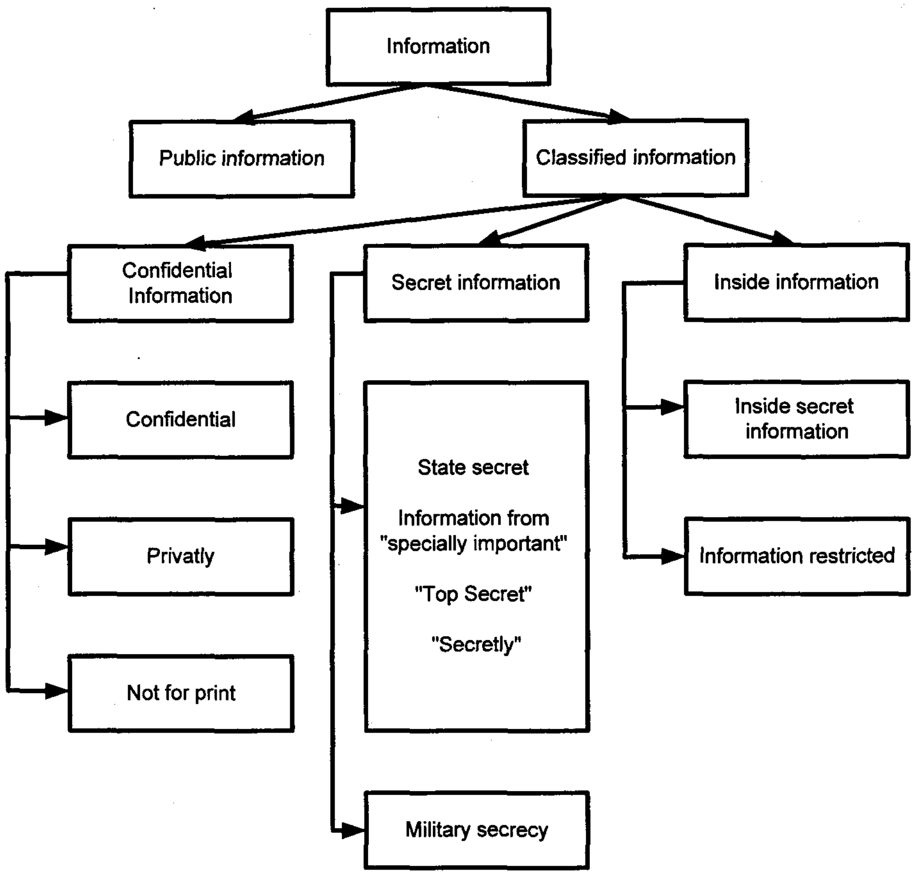

Fig. 2.1. Options of information classification

At the same time, the information is not something absolute and independent – it manifests its communicative properties only with respect to specific objects, through their interaction with the physical media.

Sources of information. We may notice that lately, due to the rapid development of information technology and improving of collection, creation, coding, transmission, transformation, processing, protection (security) and information data storage, it has came into being a new line of research – theory of information sources. We give the following definition.

Source of information is in time and space date embodiment into various nature physical media.

Sources of information in informational systems are: physical processes and natural phenomena, signals, storage media and others.

Physical components of information sources are: sensory subsystems, microcontrollers, subscriber points, researchers and operators, microprocessors, personal computers, analog-to-digital and digital-to-analog converters and other hardware-software.

Mathematical and virtual sources of information are: models, signals, algorithms, flow dynamics models of information, functional structures of hardware-software etc.

The Civil Code of Ukraine identifies sources of information: provided or prescribed by information media laws, documents, general material objects that store information – media reports, public speeches and publications. An important class are documents with limited access, determined by the Law of Ukraine "On Information" and other legislative documents. Such information contains information of confidential and secret character and must be protected against various types of breakthrough threats.

In computer science and computer technology is distinguished computer information, as the information about the objective world and the processes therein, an integrity, accessibility and confidentiality of which are ensured through computer technology and this information has proprietors and price.

We examine definitions which concern the major object of this paper study – information systems.

Information systems. Informational systems belongs to the major classes of technical systems. Practically, technical systems are either informational in a narrow sense, or have in its construction some kind of information items which correspond to subsystems that provide efficient operation of composite modern industrial complexes. For example, the systems of management of nuclear power plants, of modern aviation and transportation systems, systems of measurement, control and diagnosis, network informational systems. At the studies of the modern information systems functioning they are considered as hardware-software systems. These systems are based on the use of the following components [1, 2, 6]:

- instrumentation for various applications,
- software items, information basis of its operation are based, in its turn, on the mathematical and software resources.

In the branch of information systems, as in the objects of research on the reliability, are conducting a wide range of theoretical, simulation (modeling) and experimental (field) investigations.

Here are a number of well recognized definitions.

Information system – information servicing system which is an ordered set of organizational and informational resources, facilities, information technologies, that implements information processes in a traditional or automatic mode in order to perform an essential sequence of functions.

Information technology – a combination of methods, processes, software and hardware combined with technological sequence that provides collection, storage, processing, output, distribution (proved) of information in order to reduce the complexity of information resources usage, improving its reliability and efficiency.

Automated system – organizational and technical system that implements information technologies and integrates the computer system, the physical environment, personnel and information which is processed.

Due to the modern development of industrial production in various sectors of economy, science and technology, which is characterized by the transition from an industrial onto an informational stage of development, almost all technical systems are in fact informational.

It is known that the relevance and importance of information systems is confirmed by the following facts:

- high rate of growth of information technology in all domains of society life,
- dramatic expansion of new information sources and a wide-ranging spectrum of services to the users serviced by information systems,
- significant expansion of information data flow processed and transmitted by communication channels of information systems,
- increasing number of databases for various purposes, their standardization and integration into modern informational space,
- increasing computing power in modern information systems.

From these definitions, we can conclude that the major object of informational system research, that incorporates both hardware (technical means) and software, is information. If we look at the information that is investigating in the given information system, then such information is also referred to as an informational resource of information or the product. For the formation, transmission, processing and storage of information resource (product) the system implements information provision (dataware).

The development of information systems has greatly expanded the range of problems to be solved regarding the use of such systems. Simultaneously, specificity, properties and characteristics of information has caused significant growth of these problems. We consider some problems detailer.

In the studies of the information systems reliability, along with the providing traditional (basic) hardware-software information systems reliability characteristics it is required to ensure the system information resource (product) performance reliability.

Thus, each specific information system and its information resource are considered as a single complex at the operation reliability studies.

Below is presented a number of definitions ensuring information system operation at performing of n required function sequences determined by the features, properties and characteristics of the information resource.

The following general definitions are related to the various classes of information systems, including systems of data management, information security, information-measuring devices, digital processing and so on.

Integrity – the unity, connectedness of all parts of the system's information resource at transmitting, processing and storage as a whole.

For integrity ensuring, the information systems have to function reliably at prescribed operating modes and usage conditions, have to be repaired in case of hardware failures and occurring dataware errors.

Such terms such as system information resource integrity and the integrity of information systems can be considered as synonymic.

Accessibility – access availability, the ability to access the required system information resources during its communication, processing and storage.

To ensure the information accessibility means the system operates reliably in a prescribed mode and conditions of use and permits an object (user), which has an appropriate permissions, to exploit the system resource in the required volume and time period as it is set by authorized access permission.

Accessing the system information resource is an interaction of two objects – a user of information system and the information system as it is, as a result of that there creates authorized information flow from one object to another and/or changes in the system state.

Such access is an important part of the secured information systems safety policy implementation.

Here can be noted that the security policy is a set of laws, rules, restrictions, guidelines, instructions etc., which regulate the procedure of processing and transmissions within the systems of information security.

Authorized access to information resources is provided by the system performing the following operations or procedures.

Identification – ID assignment procedure (passwording) to the object of information system or establishing a correspondence between an object and its identifier.

Then is performed the following procedure.

Authentication – verifying procedure for correspondence of a presented to information system object's identifier, ensuring the object's convinced reality.

During the authentication the information system makes a decision:

- ID is valid,
- ID is null and this entity is not eligible for authorized access to the information system resource.

However a positive authentication decision is not satisfactory if lacking the subsequent procedure.

Authorization – a procedure for authorizing access to the specific information resources of a system and its services.

In the information systems is used an audit procedure to ensure an adequate level of control in accordance with the prescribed standards, requirements and information system functions.

Audit – the routine observation and registration processes or other activities taking place in the information system.

In systems with limited access to information resources are used more general, a comprehensive description, which is called observability. This characteristic is determined as following.

Observability – a sequence of procedures for identification, authentication, authorization and control on the information system user's (object) actions over resources.

At the studies of the information security systems resource operation, it is the resource with limited access, which needs a proper protection against internal and external threats. Therefore, reliable operation of such systems is defined as one of the major functions of secured information resource system and which is called privacy (confidentiality). It is known the following definition of information system confidentiality.

Privacy – property of a subject (a user) to exploit the information system resources only by the authorized access set rules, which makes it possible to preserve secrecy and the credibility of the available information data.

Judging by the weight given to the security functions (protection) of information system resources from unauthorized access, confidentiality ensuring is one of the most significant in comparison with other characteristics. However, the methodology of information security in information systems, which, as it was noted earlier, realized through the creation and security policy implementation, is based on procuring the basic characteristics of information resources, namely confidentiality, integrity, accessibility, observability, including authentication.

Next we consider the block diagrams of typical information system and a list of tasks to ensure the security of its information resources as examples.

Systems for information transmission. In Figure 2.2 is shown a simplified block diagram of transmissions in information systems. These are radio systems, TV and other telecommunications systems.

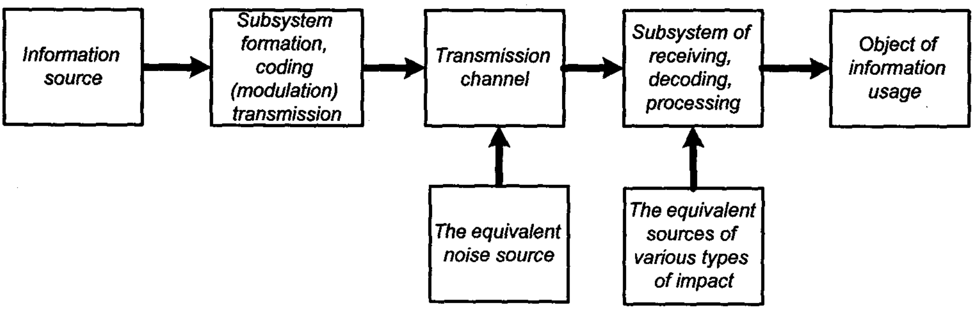

Fig. 2.2. A typical block diagram of transmissions in information system

These systems transmit both open and classified information. In the latter case, such systems are the information security systems in which is to be implemented the stated above security policy.

At public information transferring it has to be secured its integrity and accessibility.

Information measuring system. Important place in the researched quantitative characteristics and parameters determining and assessment occupy information-measuring systems, a simplified typical structure of which is shown in Figure 2.3.

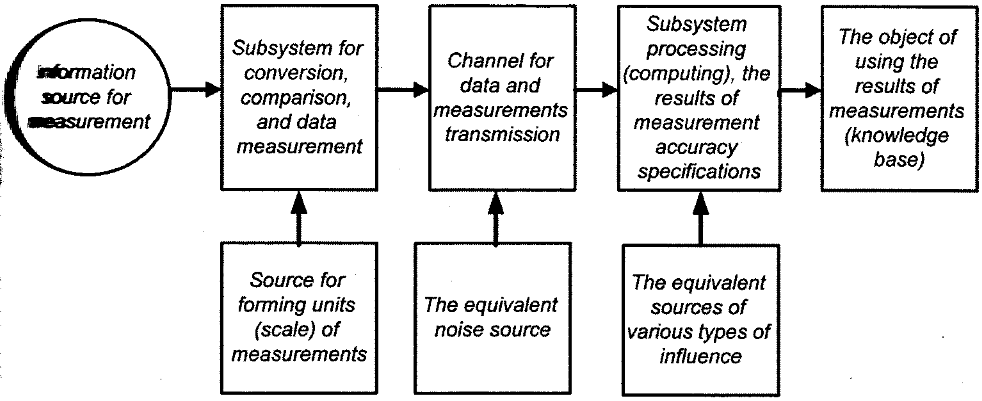

Fig. 2.3. Block diagram of an information-measuring system

A wide range of measuring, monitoring and diagnostics tasks in the information systems of varying complexity is to be solved for the systems with open and restricted information. It is also not possible to determine the quantitative characteristics and information parameters outside of the measurement process.

Information-measuring system, similarly to the systems of information transmission, must ensure the claimed accessibility and observability of information implementation.

Technological system is a set of functionally related technological equipment (machinery, equipment), means of production and performers, selected to carry out its functions at the routine conditions of production and in compliance with the specifications and technical documentation.

Technological system, as a safety system object can be found in one of the following states: operable, defective, workable, unworkable and at borderline state.

The technological system is operable if it provides manufacturing of products with required quality and the rhythm of production (productivity), according the set specifications and technical documentation at the regulated costs of material, energy and labor.

Information technology is essentially the major object of technological systems functioning in various country industrial production branches.

Typical criteria of failures (abnormal function) of technological systems are:

- inconsistency of product quality to the characteristics of the established requirements,
- decrease in performance below the set level,
- termination of the technological system operation caused by the refusal of one of the elements or factors (e.g. power supply),
- exceeding the standards for labor, cost of materials, parts etc.

Systems management. Information systems management of more composite hardware-software complexes is its integral component which is interacting in the conjunction with the other information systems operations. As an example, in Figure 2.4 is shown the simplified block diagram of the hardware-software system, which consists of information systems of measurement, monitoring, diagnosis and management.

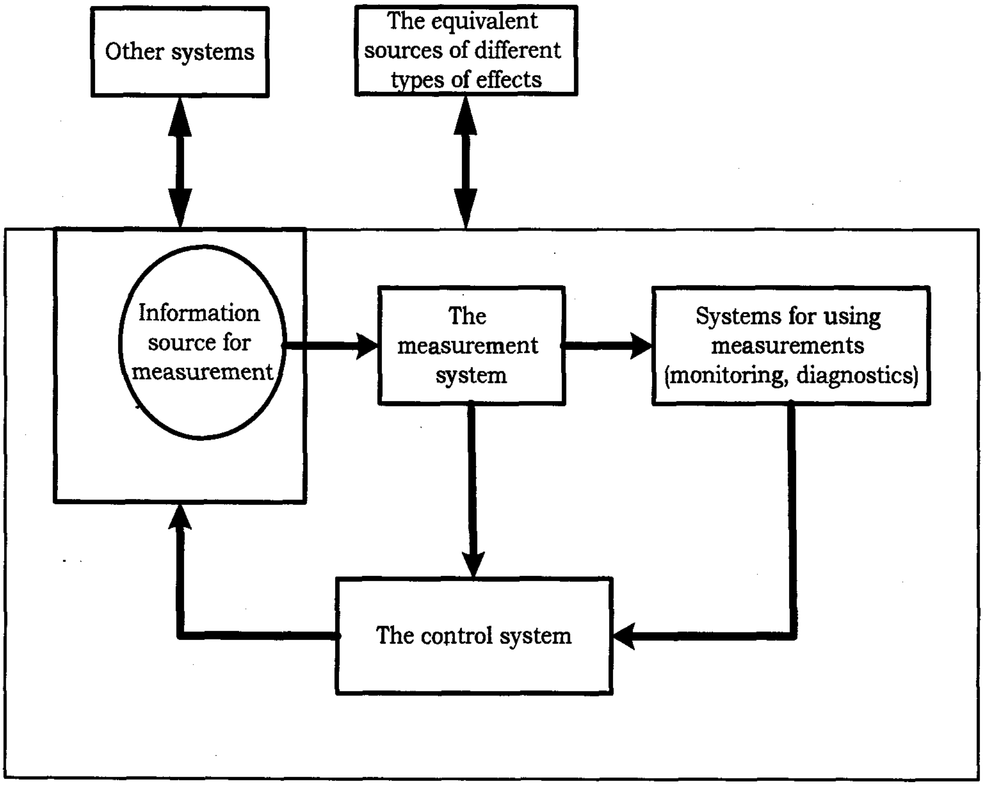

Fig. 2.4. The simplified block diagram of the hardware-software complex

Below we turn to the classification of information systems in terms of its reliability studies.

Classification of systems. In reliability studies, among information systems (products, devices, objects) are traditionally distinguished:

- non-renewable,
- renewable.

Non-renewable are called systems, which in the course of its operation and the performance of its functions cannot be repaired. If there occurred a refusal in such a system, then there stops its functions execution. Only at execution of refusal elimination (case without repair), for example by means of control, there proceeds a restoring of system functioning. Such systems include irretrievable rockets, guided missiles, satellites and others.

Examples of non-renewable systems of repeated actions include air traffic control systems, air defense systems that are on duty and other reliability characteristics of non-renewable systems were discussed in section 1.4.1.

Renewable systems are those that in the course of their operations may be repaired. If a system failure had occurred, the system stops the functions on the time of repair interval, and then the operation resumes. Reliability features of renewable systems are discussed in section 1.4.2.

At the studies on varying complexity technical systems reliability traditionally is used the following classification.

An element is a device that has no independent use and is not subjected to disassembling and repair. The elements include the items of mass production, including electronic equipment, such as integrated circuits, resistors, capacitors, relays and others.

A device consists from a set of elements that are integrated into a single structure and performs independent service functions. Examples of such devices are video monitors, televisions, personal computers, and others. The number of elements in a device can reach up to tens of thousands.

The system consists of a combination of different active devices intended to perform a specific practical problem. Systems, unlike the devices, can perform entirely new functions that cannot be solved with the use of any other devices. The number of elements in a system is hundreds of thousands, and in some cases some more.

The complex consists of a set of systems, combined for a wide range of practical tasks. In a number of modern facilities they are referred to as hardware-software systems.

If the reliability research takes into account the operation specificity, such as the level of complexity associated with the increasing of number n of functions required to perform, then it becomes applicable the following classification of devices and systems:

- items of mass production, which comprise various elements and devices,
- information systems where the major objects of study are information signals of different physical nature, which include systems of measurement, monitoring, diagnostics and control,
- complex (composite) technical systems as the hardware-software systems, which include information subsystems.

The proposed classification corresponds to the accepted in reliability theory rule, that any preceding sets of components and devices are included as the components in the following next systems classes, since information systems are the subsystems of complex technical systems (of hardware-software systems).

We consider detailer the operation of one of the specific types of information systems that are widely used in various sectors of economy. These are information security systems.

2.2. Information security systems operation analysis's the object's reliability research

2.2.1. Problems of information security

Information security systems are parts of systems, networks, information systems networks of varying complexity; they are items of modern information systems, the reliability of which plays an important role in the formation, transmission, processing, storage and distribution of information. Such systems in the studies on reliability are considered in some cases as separate items or as relevant subsystem components of larger hardware-software systems. Information security in the information systems are provided primarily by the following subsystems:

– formation, coding (modulation) and transmission,
– receiving, decoding, processing and distribution of information.

The major objectives of safety at the operation of technical (information) information security systems is to provide the following security properties information that were given above, namely confidentiality, integrity, accessibility, observability including authentication.

These safety functions of information systems are used by information security systems when exposed to aggregate internal and external threats. Among these threats can be distinguished the following:

Threats to privacy. Threats related to the unauthorized access of information are threats to privacy. If there exist restrictions on the possibility of information reading, then the relevant services of the information systems should be evaluated according to the established criteria of privacy: confidential privacy, administrative confidentiality, the reuse of objects, the analysis of covert channels and confidentiality at the exchange (export / import).

Threats to integrity. Threats related to unauthorized modification of information is a threat to integrity. If there are restrictions on the possibility of information modifying, then there considered the following items: confidential integrity, administrative integrity, the integrity of exchange.

Threats to accessibility. Threats relating to a breach in the possibility of using information systems or information processing are a threat to accessibility. If there are requirements regarding protection against refusal, of access, or protection against failure, then there are the following options for the resource use: resistance to failure, hot-swappable, recovery after failure.

Threats to observability. Identification and control over the actions of users, handling the information system services are subjected to the observability and handling. If there exist requirements for the user actions control or to the legality of access and the ability of the set protective security measures to function, then we have the following instruments: registration; identification; authentication; a trusted channel; segregation of duties; the integrity of protection complex remedies; self-testing; exchange of authentications; sender authentication (no denial of authorship); authentication of recipient (no denial of receipt).

In addition to functional criteria that help to assess the security services in information systems security there are the warranty criteria that allow assessing the services implementation correctness. The criteria of guaranties include requirements to the architecture of complex remedies security, media development and sequence of development, complex testing protection remedies, media of operation and maintenance of documentation that are hierarchical.

The levels of hierarchy reflects the incremental warranty as the assurance, that the implemented in the information system services, allow to defend specific threats and that the mechanisms that was put into operation, are, in turn, correctly implemented and can provide the expected level of consumer information safety (security) during the information system operation.

All of the described services are to some extent independent. If there is such a relationship, that an implementation of some service is not possible without implementing the other, it shows that this condition is a prerequisite for this service (or its level).

The order of information system evaluation for compliance with the set criteria is determined by the relevant regulations. An expert committee, which evaluates the information system, specifies which services and at what level are to be implemented in a given information system, and how they are complied with the guarantees requirements. The result of evaluation is a rating that appears as an ordered series of alpha-numeric combinations denoting the level of implemented services, coupled with the level of security.

Those combinations are arranged in the order of service descriptions criteria. Considering that the rating of information system can include a certain level of service or guarantees, there must be met requirements listed in the criteria for the level of service and the warranties.

The choice of security measures according to the problems and threats to the security of information systems can be made in following way:

- The first step – to identify and evaluate the safety concerns. It is necessary to consider about the requirements for confidentiality, integrity, accessibility, observability, authenticity and reliability. The strength and number of the selected security measures must meet the estimated safety concerns.
- The second step – for each security problem are defined common challenges and threats, then for each information system in question are offered safety measures. According this method it is possible to meet the specific needs for security and safety and approach the location where they are really required.
- Evaluation of safety problem – for the choice of adopted effective security measures it must taken into account the problem of security operations supported by the information system in question. Using the definition of security issues and taking into account the relevant threats that could lead to these problems, safety measures should be selected using the security policy implementation.

Evaluation of safety issues should include the information system itself, in the information stored or processed in it, and at the operations it conducts. The results will set goals for the selected security measures. Different parts of the information system or information stored or processed in it, can suffer from different security problems. It is important to link the security issues directly with the values, since they affect the threats that may be emerged, and thus influence on the security choice.

The importance of safety problems can be evaluated basing on whether security violation cause serious damage to the service, or has it suffered only from light damage, or does not effect at all.

If the information processed by the system is diverse, its various types may require special consideration. Security, which is provided to the information system, should be sufficient for all types of processed information. Thus, if some information requires a high level of safety, the entire system must be protected properly. In case when a volume of high security level information is small, it makes sense to consider this information transfer to another system, provided that it does not interfere with the service processes.

Basing on the analysis of security systems functioning, we consider the problem of information systems security loss.

Loss of privacy. We consider the consequences that can result at loss of confidentiality by malicious and/or non malicious actions. The loss of confidentiality could lead, for example, to:

– loss of public trust or reputation deterioration,
– legal liability, including liability for infringement of the data security legislation,
– adverse effects of organizational politics,
– threats to own security,
– deception,
– disruption of business relationship,
– taking wrong decisions,
– inability to perform hazardous tasks,
– financial losses,
– failure to comply with deadlines, specified in the contract,
– considerable costs for recovery.

Security policy implementation allows to estimate the losses that may result from the loss of privacy, and to decide whether such damages are significant, insignificant or zilch.

Loss of integrity. This is a loss of information that can lead to the consequences that are similar to the loss of privacy. According the results of analysis of the information integrity loss consequences, it is decided whether the relevant loss is significant, insignificant or negligible.

Loss of accessibility. Here we may consider what kind of losses may emerge due to loss of accessibility to the programs or accessibility to information, i.e. interruption of service functions which lead to the untimely response to a request or untimely execution. Should also be considered an extreme form of accessibility loss, the final loss of data and (or) physical destruction of hardware or software. For illustration, the loss of accessibility to critical applications or accessibility to critical information can lead to consequences which are indicated as a loss of privacy.

It should be noted that the amount of damages due to the loss of accessibility can become quite different in different periods of time. If this is true, then it is suitable to consider all losses that can occur in these various time periods, and to evaluate them for each period as major, minor or negligible.

Loss of observability. Corresponding losses may happen due to the loss of observability over system users or over entities (e.g., by programs) that perform user's missions. For illustration, loss of observability can lead to:

- system manipulation by the users,
- industrial espionage,
- not traceable actions,
- false accusations,
- to the consequences similar to the indicated above regarding loss of privacy.

Depending on the answers to the above matters it must be resolved whether general damages that could result from the loss observability are large, small or negligible.

All decisions regarding the loss of information security functions should be documented being as an information resource system audit mandatory rule.

Making decision on the results of damages analysis in case of information confidentiality, integrity and accessibility loss is used at grounding the hardware-software data protection measures choice.

2.2.2. Threats and safety measures for information protection

Most of information security tools are designed for a number of threats and provide protection via maintaining overall effective information security management. Below we consider separately and detailer such threats to information confidentiality, integrity, accessibility and observability for each species.

Privacy policy

Types of threats that affect privacy are listed below, along with the security measures against these threats. Selection of specific security measures is grounded according the information system type and its characteristics.

Eavesdropping. A way to access the classified media is eavesdropping (interception), for example, at the recording of information on line or telephone tapping. Security measures against this are presented below.

Physical measures. These include rooms, walls, buildings etc., making eavesdropping impossible or difficult. Another way to do this – to create noise. When using the phone some protection against eavesdropping can be provided by the appropriate cable placing.

Information security policy. Another way to avoid eavesdropping – to provide rules: when, where, and under what requirements it should be allowed information exchange.

Protection of data privacy. Another way to protect from listening in – to encrypt the message before sending.

The electromagnetic emission. Electromagnetic emission approach can be used by attackers to gain information processed by information system. Safety measures against electromagnetic emission are shown below.

Physical measures. It may be the screened rooms, walls etc., that will not allow electromagnetic emission penetration through the screening.

Safety data security. It should be noted that this is applicable to security measures only as long as the information is encrypted. For the information processing, display or printing, this type of security is not applicable.

Use of information systems with low levels of emission.

Malicious code. Malicious code can lead to a loss of privacy, for example through the interception and passwords disclosure. Security measures against it are listed below.

Protection against malicious code. Timely response to the information system disruption. Providing the timely reports about any unusual disturbances may reduce losses in the event of malicious code breakthrough. Detected code intrusions can be used to reveal attempts to gain entry into a system or network.

One of the methods to obtain passwords is an introduction of malicious code to intercept them, so it is required to provide security from such programs actions.

Network management. Another way to obtain classified material is in concealing user in flow, such as in e-mail.

Privacy data safety. Unless, for some reason, the above type of security is impossible to implement or it is insufficient, then there can be implemented additional security for the important data encryption.

The user identity concealing. User identity concealing can be introduced to avoid authentication, as well as all services and security features associated with it. As a result, it any time when the concealing enables access to the classified information it can lead to problems in privacy. Security remedies in this area are listed below.

Authentication. The concealing becomes more difficult when for the identification and authentication are used measures based on a combination of something known, something existing, and also about internal characteristics of the user.

Logical access control and auditing. Logical access control cannot distinguish between authorized users from someone who pretends to be an authorized user, but the use of access control mechanisms can narrow the sphere of such influence. Periodic monitoring and analysis of audit logs can detect unauthorized activity.

Incorrect direction/redirection of posts. Incorrect direction is a malicious or nonmalicious wrong directing of messages while its forwarding can be used both for good and evil intentions. Redirection may be conducted, for example, to maintain the accessibility integrity. Incorrect sending and reforwarding messages can lead to the loss of privacy if it allows unauthorized access to these messages. Security measures against this are listed below.

Network management. It should be used and also be implemented safety measures against incorrect direction and redirection.

Privacy data safety. In case of erroneous redirection, to prevent unauthorized access to a message it has to be encrypted.

Failures of software. Failures of software can affect the privacy security if this software protects confidentiality, for example the programs of access control or encryption, or also if the software crashes are causing loop, for instance in the operating system. Privacy safety measures in this case are shown below.

Responding to violations. Anyone who observes an incorrect operation of software should report it to a responsible person as soon as possible.

Operation. Some software failures can be avoided by testing of software before using and at utilizing the software change control.

Theft. Thefts may endanger privacy if the stolen component of information technology possesses any classified information that may become available by hijackers. Theft safety remedies are considered below.

Physical measures. It can be material resistance, the kind of making access in a building, area or room containing equipment more intricate or it may be a specific security measures against theft.

Staff. Safety by personnel (external control of personnel, confidentiality agreements etc.) must be available to hinder theft.

Privacy security policy. This security tool must be implemented if there exists a potential for equipment containing the classified information theft.

Control of information media. Any media containing classified material must be protected from theft.

Unauthorized access to information systems, data, services and applications.

Unauthorized access to information systems, data, services and applications can be a threat if someone can access any monitored materials. Security measures against unauthorized access cover appropriate identification and authentication, logical access control, audit at the level of information system and the separation of the systems at the network level.

Authentication. To prevent unauthorized access must be used suitable identification and authentication in conjunction with logical access control.

Logical access control and auditing. Must be used security tools for logical access control through the use of access control mechanisms. Periodic monitoring and analysis of audit logs can detect unauthorized activities of personnel who have authorized access to the system.

Separation of networks. To impede unauthorized access it can be done the networks separation.

Physical access control. Beside logical access control, security can be provided by the physical access control.

Control of information media. If classified data are stored within another media, for protection of these storage media from unauthorized access it should be applied media control.

Safety of privacy data. Unless, for some reason, the above type of security is impossible to implement or it is insufficient, then there may be provided additional security measures at encrypting classified data that are stored.

Unauthorized access to storage media. Unauthorized access to media that store some confidential material and their use may affect the privacy security. Means for privacy protection are listed below.

Operation. Controlling of media can be used to ensure, for example by physical security, media accounting and guaranteed removal of information which was stored, so no one could get confidential material from pre-cleaned media. Special precautions should be taken to portable media such as storage media, and paper copies.

Physical security. Adequate security of walls (strong walls and windows, as well as physical access control) and safety accessories can protect against unauthorized access.

Private data safety. Additional classified information stored on data media safety can be achieved by encrypting the material. It required a good key management system for an unperturbed implementation of encryption.

Integrity

Types of threats that can affect the safety integrity are listed below together with the safety security measures against these threats. It is known that at the choice of security tools it should be considered the information system type and characteristics.

Here can be noted that most security tools provide a "common" security, namely those focused on specific threats and provide security by maintaining the overall effective management of information safety. These measures are not described in detail and they are to be implemented for the overall effective security for each specific information system.

Damage of storage media. Spoiling the storage media threatens the information integrity stored on these media. If integrity is important, we must apply the following safety measures.

Control of information data media. Adequate control of media should include integrity checks to determine whether the saved files were corrupted.

Reservation. Reservations are needed to backup all significant files, business data, etc. If were noticed a loss of integrity, for example at media monitoring or at backups testing, then, for files integrity it must be used the back-up copy or restoring of previous copy.

Data integrity safety. For the data integrity safety on storage devices can be embedded cryptographic methods.

Mistakes in service. If services are conducted irregularly or during maintenance occur errors, the integrity of information is threatened. Integrity safety measures in this case are shown below.

Service. Proper maintenance is the best way to avoid mistakes in services. It covers documented and tested procedures for servicing and proper supervision of the operation.

Reservation. To restore the integrity of damaged data at occurring service errors can be used media backup copies.

Data integrity safety. For the information integrity safety there can be used cryptographic techniques.

Cogency. Measures for cogency should be used when it is important to have a confirmation that the message was sent and (or) received, and that the network had transmitted the message. There are specific cryptographic security tools as a basis of *cogency* (data integrity and cogency).

Failures of supply (power, air-conditioning. Supply failures can cause integrity problems same as if they had caused by other failures. For illustration, supply disruptions can cause hardware failures, technical problems or data storage media damage. Safety measures for these specific problems can be found in the relevant paragraphs, protection means against failure of supply are presented below.

Power and air conditioning. Must be used safety devices for power and air conditioning, for example, overvoltage security devices when it is necessary to avoid any problems associated with failures of supply.

Reservation. Reservations must be used to restore damaged information.

Technical damage. Technical damage, for example in the network may destroy the integrity of any information which is stored or processed in the network. Safety measures against technical damages are presented below.

Operation. Configuration and change management, as well as capacity management should be used to avoid failures in any system or network. Documentation and maintenance are used to ensure the smooth operation of a system or network.

Network management. To minimize risks of technical damage it is required to use technical methodic of operation, planning the systems and proper configuration of networks.

Electrical power and air conditioning. Should be used overvoltage safety measures for power and air conditioning, for instance protection against voltage fluctuations in order to avoid problems associated with the failures of supply.

Reservation. Reservations are used in order to restore damaged information.

Transmission errors. Transmission errors can destroy transmitted information integrity. Integrity safety measures are shown below.

Cabling. Careful planning and scrupulously cabling will help avoid mistakes, such as if an error is caused by overload.

Network management. Network equipment has to be managed properly and maintain it so as to avoid errors of transmission.

Data integrity safety. To protect from random errors in the data transmission protocols there can be used checksums and cyclic redundant codes. For the safety of data integrity from malicious attacks during transmission are utilized cryptographic techniques.

Unauthorized applications and data usage. Unauthorized applications and data endanger the information integrity which is stored or processed by the system if the programs and data were subjected by unauthorized information modification or if programs and data contain malicious code (such as of the games). Safety measures regarding this are presented below.

Safety awareness and training. All employees must be notified that they should not install or use any software without permission of the Information Security or any person who is responsible for the system security.

Reservation. To restore damaged information must be used reservations.

Authentication. To prevent unauthorized access it should be applied appropriate identification and authentication together with logical access control.

Logical access control and auditing. Logical access control must ensure that the software for processing and modification of information can be used by only authorized individuals. To detect unauthorized activity can viewing and analyzing the audit logs.

Security against malicious code. Before use all applications and data should be checked for malicious code.

User's error. User errors can destroy the information integrity. Measures of safety regarding them are listed below.

Safety consciousness and instruction. All users must be trained properly to avoid errors during operation. Such training regarding operating safety should include training regarding definitions of actions and procedures.

Reservation. Backups, for example created earlier, can be used to restore the integrity of the data that has been destroyed as a result of user error.

To the integrity of information, as well as to the privacy, threaten these actions:

- software failure,
- unauthorized access to the data media.

Safety of data integrity which are provided by the steps mentioned before, are implemented similarly to the confidentiality security measures that were described above.

Accessibility. Types of threats that may endanger the accessibility are described below in conjunction with the security measures adjacent to these threats. The choice of security measures is determined by the information system type and characteristics.

Requirements to accessibility may vary from the time non-critical data and the information technology systems up to the time-supercritical data and systems items. First it has to be protected by redundancy, whereas the latter may require the presence of system backup.

Destructive attacks. Information can be completely destroyed as a result of the destructive attacks. Security measures against it are listed below.

Disciplinary process. All employees should be warned on the consequences if they (maliciously or no maliciously) destroy the information.

Control of information media. All storage media must be properly protected from unauthorized access by using physical protection; this is in account for all information storage media.

Reservation. It should be made backup copies of all important files and business data etc. If the file or any other information is not available (for whatever reason), to recover the information has to be used a backup or a preceding backup copy.

Financial security. To prevent unauthorized access, to facilitate the unauthorized destruction of equipment or data, it must be used a physical access control.

Authentication. Suitable identification and authentication to prevent unauthorized access should be used along with the logical access control.

Control and audit logical access. Control of logical access must ensure that there is no unauthorized access to information, which could destroy it. Viewing and analyzing of the audit logs can help to detect unauthorized activity.

Failures of communication equipment and services. Crashes of communication equipment and services threaten the information accessibility transmitted through these services. Depending on the cause of failure it may be helpful to use to "Software failures", "Supply failures' or "Technical fault" relevantly to the system technical documentation.

Excessivity and redundancy. Excessive introduction of communicating services components may be used to reduce the likelihood of exchanging services failures. Depending on the magnitude of the maximum allowable downtime, to meet this requirements, there can also be used an additional equipment. In any case, to ensure accessibility in the event of an emergency, the configuration data and its location should also to be reserved.

Network management. Network equipment has to be managed properly and maintained so as avoid errors.

Cabling. Careful planning and cabling can prevent damages, if it is suspected that a contour line may be damaged, such version has to be checked.

Cogency. If there is required network sending or receiving messages confirmation, there must be applied cogency, then a damaging of communication utilities or missing information can be easily detected.

Fire, flood. Equipment and information can be destroyed by fire and (or) water. Safety measures against fire and water are presented below.

Physical security. All buildings and rooms containing equipment or media that store important information should be adequately protected from fire and water.

Business continuity plan. For the security of business from the devastating effects of fire and water it should be developed an appropriate plan for the business continuity and made affordable backups for the important information.

Misuse of resources. Misuse of resources may result to an inaccessibility of information or service. Safety measures regarding these items are presented below.

Staff. Entire staff should be warned about the consequences of misuse of resources, if necessary, there should be imposed disciplinary measures.

Operation. To detect unauthorized activity, the system needs to be supervised, and to minimize the possibilities of privileges abuse it has to be carried out a distribution of responsibilities.

Authentication. Suitable identification and authentication should be used alongside with logical access control to prevent unauthorized admission.

Logical access monitoring and auditing. It is recommended to use protection for the logical access control via the use of access control mechanisms. Viewing and analyzing of the audit logs can detect an unauthorized activity.

Network management. To minimize opportunities regarding the network resources mistreating there must be implemented an appropriate network configuration and partitioning.

Natural disasters. To provide security against loss of information and services as a result of natural disasters it should to be applied the following safety requirements.

Safety regarding natural disasters. All premises should be protected so stern as it possible against natural disasters

Business continuity plan. There must be available and fully tested business continuity plan for each building-premise, made a backup of all important information, should be available appropriated services and resources.

Channel congestion. Channel congestions threaten the information accessibility that is transmitted through these channels. Accessibility safety requirements are presented below.

Congestion and redundancy. Excessive implementation of communication services can be used to reduce the likelihood of communication services failures. Depending on the dimension of the maximum allowable downtime, auxiliary equipment can also be used to meet the prescribed requirements. In any case, to ensure accessibility in the event of an emergency the configuration and the location data should be also reserved.

Network management. To avoid overloading there must be implemented an appropriate configuration, management and administration of networks and communication services.

Safety observability, authenticity and reliability measures. Scopes of observability, authenticity and reliability applications are very diverse in particular areas. These differences mean that there can be applied many specialized security measures. So here below are general guidelines.

Safety measures that provide "general" security are directed to a number of threats and provide protection through maintaining the overall effective information security management.

For the reason of that, they are not presented here, but their influence should not be underestimated and they should be implemented for the effective overall protection.

To the information accessibility, as well as to its confidentiality and integrity can threaten the following events:

- storage medium damages,
- errors in service,
- malicious code,
- concealing the user identity,
- improper referral / messages redirect,
- failure of software,
- disruptions of supply (power supply, air conditioning),
- technical damage,
- theft,
- transmission errors,
- unauthorized access to information systems, data, services and applications,
- use of unauthorized applications and data.

Observability. For the information observability protection it must be considered any threat that may lead to the inability to associate some event with a specific object or subject. Some examples of such threats are: a shared account use, concealing of an individual user, software failures, and unauthorized access to information systems, data, services and applications, as well as weak identity authentication.

There are two types of observability to be considered. One is related to the definition of the users responsible for specific actions over information and information systems. This function is performed by audit logs. Another type is associated with mutual identification between users on the system. This can be completed in the course of the cogency service, by splitting knowledge and double control.

Any threat to observability, and therefore the system or process not assuring about the object authenticity, can be abridged, For illustration, any hazard that can create this situation will contain unclassified data changes together with untested source data and also the data source that is not supporting the observability, and therefore the system or process is not confident about the object authenticity and can be abridged.

To facilitate implementation of authenticity or its accomplishment there can be used a large number of security tools. There can be used a range of measures from the signed reference data, control and audit of logical access up to the use of digital signatures. The choice of specific security measures will depend on the specified use on a particular area authentication.

A large number of security mechanisms can be used for cogency implementation or to contribute into its completion. Here can be used tools that depend on the following factors: security policy, safety measures for awareness and monitoring, auditing the logical access to the one time passwords and control media. Implementation of ownership information policy is a prerequisite for observability. The choice of such specific security measures will depend on the use of observability defined for a particular area.

Any threat that may lead to inconsistent behavior of systems or processes will reduce the reliability level. These threats concern system performance and unreliable service. Loss of reliability may occur at low-level customer service quality or at the loss of customer confidence.

For implementing the reliability or to contribute into its realization there can be used many remedy measures. There can be used such mechanisms as making business continuity plans, introduction of redundancy in the physical architecture, the system identification, authentication, audit and logical access control maintenance. A choice of specific security measures will depend on the specified use of authentication in a particular area.

2.3. Reliability characteristics classification

Here is presented the following classification of reliability technical characteristics and, in view of that, the same for informational systems.

Classification of reliability characteristics. According to the purpose all the reliability characteristics of objects are functional because they reflect (define) the object ability to perform those functions in its operation. In its essence, each characteristic of particular item reliability is an individual one.

At the first stage of the foundation of reliability engineering and information systems as a science, there were established basic theoretical and practical positions using a particular measure for the reliability characteristics, such as the probabilistic assessing approach for the whole class of technical systems.

Using the probabilistic assessment for any technical systems of varying complexity allows identify a subset of reliability characteristics for the systems that have been presented in the first section of this book.

Such reliability characteristics can be called *basic* or *classic*.

In the subsequent stage of the reliability basics development it was required to determine a number of basic specialized reliability features that could perform more effective analysis of functioning probability item in order to improve its operation reliability.

Examples of such specialized descriptions are characteristics of metrological reliability of measuring instruments; the number of publications on the results of such research recently was significantly increased. There can be predicted special features of research concerning other technical systems. Namely, information security systems reliability performance characteristics ensure its confidentiality, integrity, accessibility, authenticity and observability.

Based on this we give the following technical systems performance reliability classification, as they are:

- basic for all systems class;
- specialized for different subsets of systems, each of them incorporate the relevant brands of operation and definite class of problems solving, including:
  a) various sectors of the national industry, science and technology (energy, transport, radar equipment, medicine, nuclear physics etc.),
  b) various physical principles of operation (acoustic, electromagnetic, optical etc.),
  c) operational services of different tasks (detection, identification, spectral correlation, measurement, adaptation, management etc.).

Graphically the demonstrating schemes for the proposed performance reliability of technical systems classification are given in Figure 2.5.

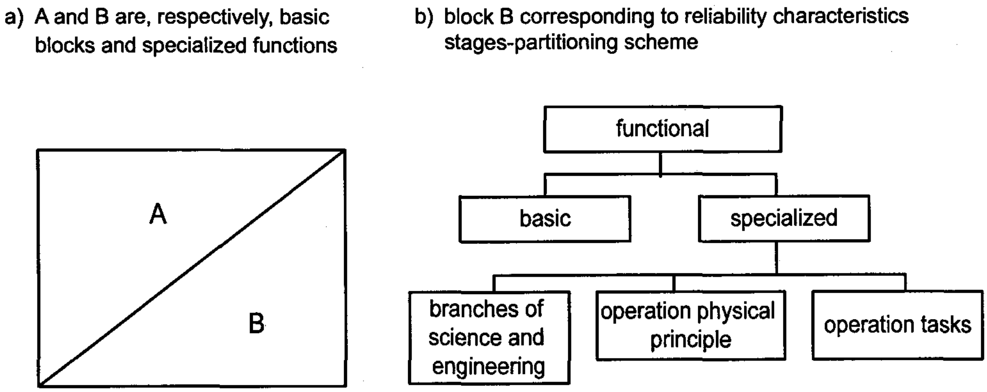

Fig. 2.5. Illustrative classification scheme of functional reliability characteristics

It can be noted, that there are two fundamentally important steps in functional objects reliability characteristics determining, and they have been discussed specifically in the first chapter:

- definition of calculative reliability characteristics on the results of theoretical and simulation studies (direct problem of reliability);
- definition on experimental values and their coordination with the design reliability characteristics (inverse problem of reliability).

thus, to ensure highly reliable facilities operation it should be defined a wide range of safety measures, such as combining both basic and specialized reliability characteristics. To confirm this conclusion, we give below some specific examples.

Example 2.1. Notice that in the information systems reliability studies can be roughly distinguished two blocks of reliability characteristics:

A) reliability characteristics of hardware-software systems that reflect the specific modes of operation, conditions of the system in use;

B) reliability characteristics of information resources that reflect the collection, creation, transmission, processing and information data storage specificities in terms of internal and external threats.

Naturally, in the studies of the information systems reliability it has to be conducted research of the unit blocks (A) and (B) reliability characteristics simultaneously.

We may concretize block (B) reliability characteristics of information resources.

Under information reliability in informational systems is meant an ensuring the following characteristics:

- *integrity, i.e. no change, distortions and destructions of information elements,*
- *confidence in the information – observability, that is no unauthorized modification, no substitution of information pieces while maintaining its integrity,*
- *information accessibility, which is providing by the system to the authorized users some looked-for information in the required quantities and time,*
- *information security – reassurance, that there is no its unauthorized obtaining by users or by processes which do not possess an appropriate legal rights,*
- *preventing the information unauthorized reproduction and transmission.*

Speaking from the point of view of the information system, in order to ensure the reliability characteristics of block B) the system must perform an appropriate sequence of essential functions. Such problem of information resources security is to be solved on a case to case basis. Here may be noted that for assessing the ability of information system to perform a sequence of essential functions will be using appropriate criteria of information security, namely the performance of two types of requirements:

- functional requirements to the security services provided by the system,
- requirements to guarantee the information protection.

The named criteria are listed in the official regulations, including the ND TZI 2.5-004-99 "Criteria for evaluating information security in computer systems from unauthorized access".

Example 2.2. In the studies of various types of power plants, including nuclear, thermal, hydroelectric, wind, solar and others were defined:

- standardized basic reliability characteristics for all kinds of power plants;
- special reliability characteristics:
  a) metrological characteristics of electrical power quality reliability parameters, for all kind of power plants;
  b) specialized parameters in the reliability characteristics for the secure operation for each type of power plant – namely its environmental performance, for example radiation emission intensity (level) for the staff, environment and others.

Below we briefly discuss the general properties of information signals, which, as it was noted earlier, is the major subject of information systems research.

2.4. Information signals at the system reliability characteristics identification

Information signals compose the starting place to determine information system reliability characteristics. To the basic knowledge of this fact and materials is devoted this unit.

In some cases, an information system is the major instrument in the study of the reliability examined objects as it is shown in Figure 2.6.

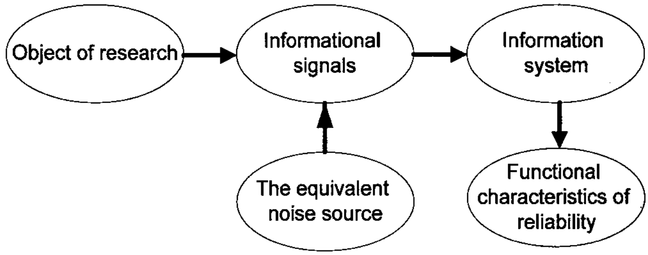

Fig. 2.6. Scheme of basic reliability components determining examined object characteristics relationship

First there can be considered the general case and classifications types (options) for the formation and transformation of informational signals in the technical systems:

- signal is created (generated) by the system itself, with subsequent conversion within the corresponding links, modules, and subsystems to form the output signal,
- signal is fed as an input of the system, following by its transformation in the links of the system and output signal formation,
- signal from excitation source is fed as the input of the system as an excitation signal (test signal), which, in turn, generates the corresponding informational signal, formation and transformation of which is determined by the characteristics and properties of the technical system.

Illustrative scheme of formation and transformation for the specified classes of such signals within information systems are shown in Figure 2.7 for the corresponding options (a, b, c).

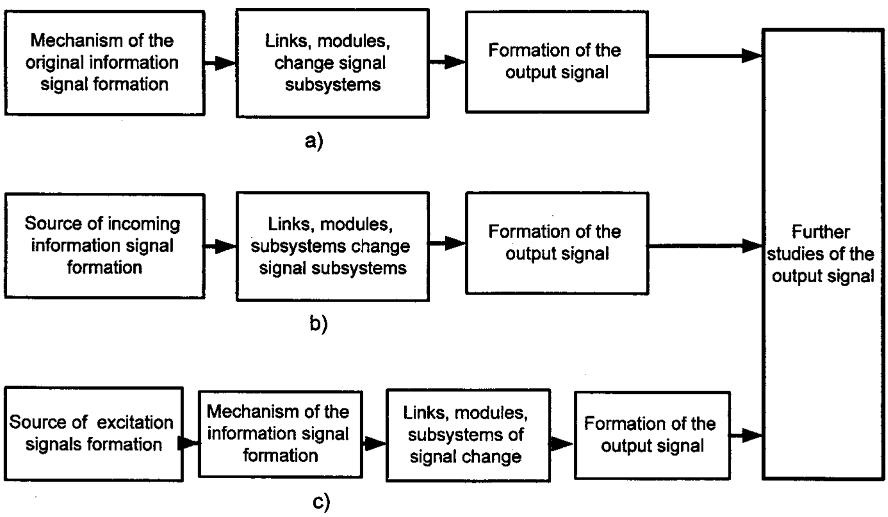

Fig. 2.7. Block diagrams of variants of signals formation and transformation in information systems

At converting signals inside information systems can be allocated the following tasks:
– analysis;
– synthesis.

Objectives of analysis. We consider here the known from the theory of signals and systems three tasks, regarding signal change analysis in systems, namely the problems:
– direct,
– inverse,
– identification problem or "black box."

For the problems concerning signal changes in systems specified analysis we use the following illustrative structure which is shown in Figure 2.8.

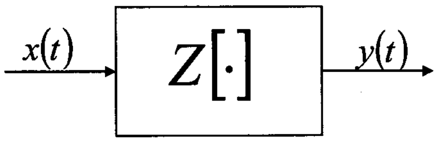

Fig. 2.8. Scheme of signals change in a system

In Figure 2.8 are used the following notations:
– $x(t)$ – input or generated by the system signal (action),
– $y(t)$ – output signal (response),
– $Z[\cdot]$ – operator that describes the system of signal transformation.

We know that as an operator $Z[\cdot]$ are using linear and nonlinear operators, which respectively characterize the studied system and are in most cases the differential or integral operators. For example, a linear system with constant parameters over time and pulse transition function $\varphi(t)$ is described by the linear operator:

$$L[\cdot] = \int_0^t \varphi(t-\tau)\cdot d\tau \tag{2.1}$$

the response of such system is described by the following expression:

$$y(t) + L[x(t)] = \int_0^t \varphi(t-\tau)x(\tau)d\tau. \tag{2.2}$$

Below we formulate more extended set of the said signals conversion analysis problems.
Direct problem: is given $x(t)$ and $Z[\cdot]$, it is required to determine $y(t)$.
Inverse problem: is given $y(t)$ and $y(t)$, it is required to determine $Z[\cdot]$.
Identification problem: is given $x(t)$ and $Z[\cdot]$ it is required to determine $Z[\cdot]$.
If we use the general approach of the theory of signals and systems, then the problem of determining the reliability characteristics for the examined information systems relates to the problems of identification.

In the majority cases the identification problems are bound to the tasks of the examined objects during its reliability characteristics analysis and are being resolved at the subsequent stages of the item life cycle:

- at the design phase of an object, particularly at conducting the theoretical and simulation studies of different options during the object construction (building of models, computing the reliability characteristics as a result of direct problem solution);
- at the stage of the objects operation full-scale tests (obtaining reasonable experimental reliability characteristics as the result of inverse problems solution)

Synthesis problem. Formulation of technical systems synthesis problem as of research goal for the objects reliability is given in Figure 2.8:

- there is given:
  - entrance, or generated by the system itself input signal $x(t)$,
  - reliability characteristics of the system,
  - optimality criterion (efficiency) which usually provides maximum or minimum value of one or more characteristics of the system reliability described with operator $Z[\cdot]$ at system performing functions expressed by the response $y(t)$.
- it is required to find a pattern of the operator $Z[\cdot]$ implementation, for which it could be realized the reliability characteristics optimality criterion at the signal $x(t)$ input.

The problems of analysis and synthesis of reliable technical systems are interrelated and there take place two cases:

1) at creating a new technical system it is first solved the problem of synthesis – creating a pattern for the operator implementation $Z[\cdot]$, after that, there investigated the problem of analysis, since optimality criterion does not optimize all reliability characteristics of the system, so in many cases, in practice, takes place implementing of so-called system quasi-optimal structures;
2) at the study of a formatted, but unknown structure of a system are investigated mainly the problems of analysis – that is, the problems of system reliability characteristics identifying.

Below we consider the information signals and noises problems that occur in the tasks of systems performance reliability research.

Distinguishing between data and informational signals and noises is arbitrary, and is determined at the measurement problem formulation. Thus, for some problems – processes of thermal, shot and flicker noises generated in electronic systems are the focus of information signals research, while for the others just troubles. As an example, here can be presented the following classification of signals (noise): the natural, terrestrial, including pulsed atmospheric discharges; seismic and geophysical disturbances; hydroacoustic noise fields; electromagnetic radiation of diverse terrestrial objects; phenomena of no terrestrial origin – the cosmic radiation of the Sun, stars and other celestial objects; industrial – radiation both electromagnetic and vibrational, acoustic, optical frequencies in a wide energy range, from avionics to mechanical systems etc.

The following example is typical for the problems of electromagnetic compatibility at a collective functioning of radar, radio communications and other electronic systems, such e.g. as in the surface warships, i.e. in the areas of such located systems simultaneous utilizing. This case of systems operation can serve as a concrete example, as for a certain system a signal is informational, but for others – nuisance.

Physical nature of the signal formation in most cases is stochastic, random and according to the classification A.M. Kolmogorov's there are three possibilities:

- a signal can be described by deterministic models that are independently determined by the initial state of affairs, but the initial requirements itself are random,
- the signal as a function of time and/or space is a random variable which is described by a random process or by a random field,
- sequential dynamics of a signal for different combinations in most cases is described by the additive or multiplicative mixture of deterministic signals and random processes.

These options of random signal are essentially define both the signal itself, and also its possible more complex forms as the combinations of signals.

It is known that to the major objects of mathematical modeling belong stochastic processes, and in the process of mathematical modeling it is used triad "model-algorithm-program" named by the soviet scientist A.A. Samara. At the primary stage it has to be grounded a mathematical model of a particular signal, and at the subsequent stages are developed algorithms and created the appropriate software for the computational experiments based on the computer technology resources. Mathematical modeling has some advantages over the conducted using the system's existing information experimental base, however it has some interrelated restrictions.

At using the known signals and noise study results it is proposed to consider, along the set of physical mechanisms, a creation of signals under action of random factors from some two generalized sources (generators) for the formation of:

- a sequence of harmonic oscillations with random parameters, namely random amplitudes and phases and, in general, functions of time,
- a sequence of pulses with random parameters, namely random values of duration, intensity and period of repetition within the observation time interval.

It is believed that a signal is generated and distributed (transmitted) inside a limited spatial region, and signal process formation and accumulation is the sum of the said components sequences, therefore the signal is forming in the spatial region where applied the principle of superposition.

2.4.1. Classification of information signals

The term "signal" comes from the Latin *signum* – sign and has extensively large connotation. The signal is understood as a process of knowledge about an object or natural phenomenon physical transfer in time and space. The term "signal" is also used in the mathematical model of signals, as about a physical process.

The terms "information signal", "measurements signal" and "signal" are used in this paper as synonymous terms, and the specific meaning of a "signal" is determined by a problem specific formulation.

In order to specify the assigned signal at the information systems reliability research we present initially in Figure 2.9 the following classification of signals.

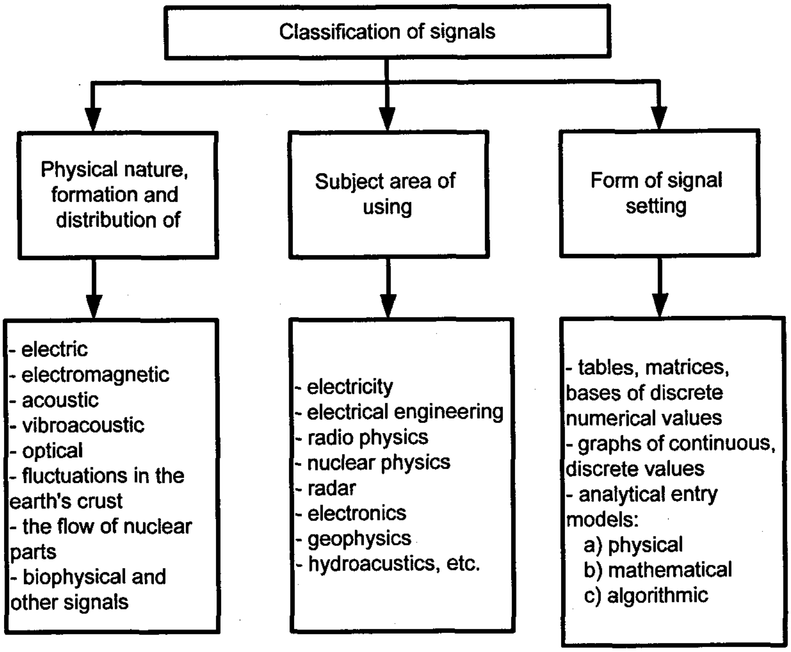

Fig. 2.9. Classification of signals

At formulating and solving information systems reliability problems it is mainly used the following, shown in Figure 2.10, classification of signals mathematical models.

Information signals in the reliability problems. Based on the studies of information signals here can be defined the calculated and experimental characteristics for the examined system reliability, that is for the solution of direct and inverse reliability problems.

For the formulation and solution of reliability tasks is used an informational background, including: mathematical; software.

Informational support – a summation of observed experimental data base, the results of measurement, monitoring, diagnosis and management, file structures and directories together with management tools, information security against unauthorized access processing features, as well as mathematical and software background.

Mathematical software – an aggregate of mathematical models, methods and algorithms upon which a technical system performs its tasks associated with the intended purpose.

The software implements mathematical support and has two major components: the system and the functional software.

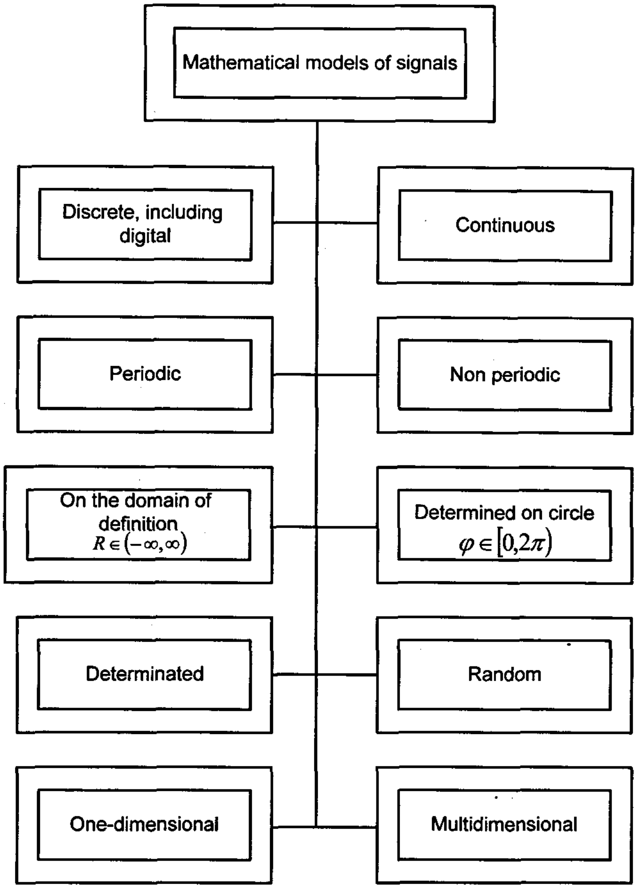

Fig. 2.10. The major types of the signals mathematical models for the information systems reliability problem solving

A mathematical model of the examined object is one of the major components of the above mentioned types of provisions. In this book first section was given the definition of the mathematical models as of embodiments of knowledge, associated assumptions, hypotheses and conditions which homomorphically reflects object of study major features and characteristics.

We may consider the stages of mathematical models designing and use:

- recording, using mathematical objects, symbols and basic laws of facility operation based on the study of a priori information about the objects, taking into account the classes of problems;
- conducting theoretical and simulation studies for simulation modeling using mathematical model (direct problem of reliability);
- models use to solve application problems, including experiments conducting (direct and inverse reliability problems);

- coordination of theoretical and simulation studies with the real experiment based on the proposed model, which enables to make a decision with respect to the mathematical model, selecting one of the following:
  - use of the proposed models for future research,
  - improvement of the proposed model,
  - new model development.

2.4.2. Baseline signals at the information systems reliability characteristics identification

Methods for determining the reliability characteristics of engineering systems are described in the large number of publications.

Formulating the problems of examined system reliability characteristics identification or the problem of "black box" identification was presented in the section 2.4 in following wording:

- at given input signal $x(t)$ that was fed into the input of the researched system, then the output signal of the system $y(t)$ is the response of the system,
- basing on the given signals $x(t)$ and $y(t)$, $t \in T$ to find characteristics of the system.

The general formulation of the information systems reliability characteristics identification problem is different from the general problem of identifying the characteristics of a "black box"; in essence it is a dissimilar case. This is due to the following:

- at the design stage and at subsequent stages of the life cycle of the system are to be determined calculative and further statistical estimations of a real system operation, which have to be determined basing on relevant reliability characteristics;
- the following properties are defined during simulation, measurement and field experiments, by using the following standard classes of the input information signals:
  - harmonic and polyharmonic,
  - pulse, including signals type delta functions,
  - realizations of stochastic processes, including processes of white noise realizations, that adequately describe both the structure and characteristics of the "black box" of the examined information system, especially of its hardware.

Programming complex of an information system at the development, debugging and testing processing is also using the mentioned common classes of information signals. Here also, as for information signals are used mostly random processes implementations, the formation of which will be discussed in the next section.

2.5. Reliability problems stochastic processes modeling

The theory of stochastic processes is used for the study of physical signals, noise, technical processes that change over time and therefore are random. The essence of its use is, above all, in that a certain random process is considered (usually with a grounding) as a mathematical model of real physical or technical process which is used for the technical systems reliability problems solution.

Compliance with this model is largely determined by the success of simulation studies. This is especially true for the composite technical systems, including aviation and space systems, nuclear energy and others. Test of a system on reliability in some cases is unworkable, in some cases it is due to the significant economic, time and maintenance costs. Therefore, simulation experiments, which are, as a rule, computer assisted, play an important role at the scientific and technical systems reliability problems solving. Simulation models of signals are used at testing of technical systems, at testing and prediction problems solving, in a variety of training systems, such as regarding the aviation training apparatus and others.

Simulation of random processes is carried out according the general approach known as the method of statistical tests (or Monte Carlo method). Technical instrument for simulation of random processes is in the employment of computer technology, including information systems. Because of discrete character of information system studies, its usage allows to modeling usually random sequences (processes with discrete time) which, if necessary, can be approximated (by analytical method or technical means of digital-to-analog conversion) in order to build continuous time random processes models.

Simulation of stochastic process using statistical tests is reduced essentially to the constructing of an algorithm for generation with this information system its processes implementations and it requires the following major problem solutions:

- generation of implementations, in a sense of the simplest random sequence, that required to simulate actual randomness,
- interpretation of simulated process into constructional (from Latin *constructivus* – one that is used for building) form in order to obtain it by the above mentioned simplest random sequence conversion,
- verification of coincidence (or at least a certain proximity) of probabilistic characteristics of a random process and its simulation model.

In this section we consider the most common in practice applications of methods for the first two problems solving. The latter problem is solved by the methods of mathematical statistics, which will be discussed in the section three.

2.5.1. Modeling of pseudorandom numbers sequences

Let $\xi(\omega), ..., \xi_n(\omega)$, $\omega \in \Omega$ is a sequence of independent random variables (white noise in the narrow sense); each of them has a uniform distribution with parameters $a = 0$, $b = 1$ and probability distribution density $f(t)$

is defined as: $$f(t) = \begin{cases} 1, t \in [0,1], \\ 0, t \notin [0,1]. \end{cases}$$

When using the method of statistical tests the introduced above sequence is called the *random numbers.*

The major problem of simulation modeling of random numbers (and in general of any random elements) in the information system is that all modern information systems operate according to certain algorithms specified for software or hardware.

To implement stochastic experiment for the universal purpose information system using any algorithm is essentially impossible. Therefore, instead of random numbers are using so-called *pseudorandom numbers n*, that are obtained by entirely coincidental algorithm but possessing some properties that are very similar to those of random numbers realizations.

One of the best studied in theoretical terms and used in practical application as a method to generate pseudorandom numbers is *method of residues (linear congruent method)*, according to which, at first it is received a sequence of positive integers u_0, u_1, u_2, ..., u_n, ... according recurrent algorithm of the form:

$$u_n = (u_{n-1}M)(\text{mod } N),\ n = \overline{1, \infty}, \tag{2.3}$$

where u_0, M, N – *a* set of mutually simple natural numbers, $A(\text{mod } B)$ – the residue after dividing the numbers A/B, for example, 22 (mod 5) = 2, and a sequence of pseudorandom numbers α_0, α_1, α_2, ..., α_n, ... derived from (2.3) as:

$$\alpha_n = \frac{u_n}{N}, n = \overline{1, \infty},\ 0 < \alpha_n < 1, \forall n. \tag{2.4}$$

Residue method is also used in a slightly different (more general) form than in (2.3) and (2.4), namely, the sequence $\{u_n\}\}$ is formed as

$$u_n = (u_{n-1}M + M_2)(\text{mod } N),\ n = 1, 2, ..., \tag{2.5}$$

where u_0, M_1, M_2, N – positive integers, and the sequence $\{\alpha_n\}$ is computed according to (2.4).

The algorithm obtained at $M_1 = 69{,}069$, $M_2 = 1$, $N = 2^{31}$ is considered as one of the best and is used in the production of well-known companies, manufacturers of software.

How well pseudorandom numbers imitate the implementations of random numbers can be checked using the methods of mathematical statistics and special methods of the numbers theory.

Sequence of independent, uniformly distributed in the interval [0, 1] random variables, is in fact the simplest case of random sequence, by corresponding transformations of which there can be obtained other, more complex stochastic processes.

2.5.2. Modeling of random processes typical sequences

Solution to the problem of reliability through computer simulation experiments is based on the use of a particular methodology: problem statement is based on grounded mathematical models for an object, algorithms for development and computational experiments software. Modern information technology of computer simulation largely uses the powerful software modules such as Mathlab, MathCad etc., within those the formation of random processes sequence is a formalized parametric procedure. This formalization on one hand simplifies operations at computer simulation problem solving, but in terms of gaining knowledge of different levels for the training of students and researchers, this formalization (using the software of the "black box") does not meet the requirements of the learning process. Therefore, in this paper are given the major provisions forming the typical sequence of random processes that are used in reliability problems.

Simulation of white noise with continuous distributions. Universal modeling method of continuously shared white noise is specified by the following.

Statement. *Suppose that* $\alpha(\omega)$ *– random variable uniformly distributed in the range of* [0, 1], *and* $F(t)$ *some continuous distribution function. Then the random variable* $\xi(\omega) = F^{-1}(\alpha(\omega))$ *(where* $F^{-1}(t)$, $t \in [0,1]$ *– function inverted to the* $F(t)$ *has the distribution function* $F(t)$.

The distribution function of a random variable $\xi(\omega)$ looks like

$$F_\xi(t) = \mathbf{P}\{\omega \in \Omega : \xi(\omega) < t\} = \mathbf{P}\{F(F^{-1}(\alpha) < F(t))\} = \mathbf{P}\{\alpha(\omega) < F(t)\}.$$

The distribution function of a random variable $\alpha(\omega)$ has form

$$F_\alpha(y) = \mathbf{P}\{\alpha(\omega) < y\} = \begin{cases} 0, y < 0, \\ y, 0 \le y \le 1, \\ 1, y > 1. \end{cases}$$

Therefore

$$F_\xi(t) = \mathbf{P}\{\alpha(\omega) < F(t)\} = \begin{cases} 0, F(t) < 0, \\ F(t), 0 \le F(t) \le 1; = F(t), \\ 1, F(t) > 1. \end{cases}$$

So, if to model the sequence $\{\alpha_j(\omega), j = \overline{1,m}\}$ then the simulation of sequence $\{\xi_j(\omega), j = \overline{1,m}\}$ of independent random values, each of them is continuously distributed with the distribution function $F(t)$, is carried out as following: $\xi_i(\omega) = F^{-1}(\alpha_i(\omega))$, $i = 1, m$. The described algorithm is called the *method of inverse functions.* The major problem in this method practical implementation is to determine the function $F^{-1}(t)$ for the given distribution function $F(t)$.

For a number of important distributions, this problem can be solved without much difficulty. In particular, by simple analytic transformations here can be obtained the inverse functions for:

- uniform distribution $F^{-1}(t) = (b - a)t + a$,
- exponential distribution $F^{-1}(t) = -\dfrac{\ln(1-t)}{\lambda}$,
- Rayleigh distribution $F^{-1}(t) = \sigma\sqrt{-2\ln(1-t)}$,
- arcsine distribution $F^{-1}(t) = \alpha \cos(\pi(1 - t))$.

Thus, an algorithm of modeling of stationary white noise that uniformly distributed in the interval $[a, b]$ has form $\xi_i(\omega) = (b - a)\alpha_i(\omega) + a$, $i = \overline{1, m}$.

Here may be noted that the distribution function of a random variable $1 - \alpha(\omega)$($\alpha(\omega)$ is random variable with uniform distribution in the interval [0, 1]) and is:

$$F_{1-\alpha}(t) = \mathbf{P}\{1-\alpha(\omega) < t\} = \mathbf{P}\{\alpha(\omega) > 1-t\} = 1 - F_\alpha(1-t) =$$
$$= 1 - \begin{cases} 0, 1-t < 0; \\ 1-t, 0 \le 1-t \le 1; \\ 1, 1-t > 1; \end{cases} = \begin{cases} 1, t > 1; \\ t, 0 \le t \le 1; = F_\alpha(t). \\ 0, t < 0 \end{cases}$$

That is, the random variables $\alpha(\omega)$ and $(1 - \alpha(\omega))$ have the same distribution.

Hence we obtain the following algorithm of simulation for stationary white noise with an exponential distribution: $\xi_i(\omega) = -\frac{\ln\alpha_i(\omega)}{\lambda}$, Rayleigh distribution: $\xi_i(\omega) = \sigma\sqrt{-2\ln\alpha_i(\omega)}$, distribution of arcsine: $\xi_i(\omega)$ α $\cos(\pi\alpha_i(\omega))$, $i = \overline{1, m}$.

However, for many distributions to obtain the inverse function in a form of a simple analytical expression is not possible. In such cases it is attempted to find such an operator $A[\cdot]$, in which presents $\xi_i(\omega) = A[\xi^{(1)}(\omega), \xi^{(2)}(\omega), ..., \xi^{(n)}(\omega)]$, where $\xi_i(\omega)$ – white noise, which has to be modeled and $\xi_i^{(1)}(\omega), \xi_i^{(2)}(\omega), ..., \xi_i^{(n)}(\omega)$ – are white noises (simulation models of which are easy to obtain by method of inverse functions), or there use the approximate methods of simulation.

An example of the distribution, for which it is impossible to find a simple expression of the inverse function, is the Gaussian distribution. To simulate white noise with Gaussian distribution can be used the following.

Statement. Let $\alpha(\omega)$ i $\eta(\omega)$ be independent random variables, while $\eta(\omega)$ is uniformly distributed in the interval [0, 1] and $\eta(\omega)$ has a Rayleigh distribution with the parameter σ. Then the random variables $\xi_1(\omega) = \eta(\omega)\sin(2\pi\alpha(\omega))$ and $\xi_2(\omega) = \eta(\omega)\cos(2\pi\alpha(\omega))$ are independent and have the same Gaussian distribution $N(0, \sigma)$.

Thus, the algorithm of simulation of stationary white noise with distribution $N(0, \sigma)$ will look like that. We generate sequence $\alpha_i(\omega)$, $i = \overline{1, m}$ and divide it into two subsequences, such as: $\alpha_j^{(1)}(\omega) = \alpha_{2k+1}(\omega)$ and $\alpha_j^{(2)}(\omega) = \alpha_{2k+1}(\omega)$, $k = \overline{1, m/2}$ (it can certainly generate a sequence $\{\alpha_j^{(1)}(\omega)\}$ and $\{\alpha_j^{(2)}(\omega)\}$ by different algorithms). After that, it can be modeled two sequences of independent white noises with distribution $N(a, \sigma)$ as following:

$$\xi_i^{(1)}(\omega) = a + \sigma\sqrt{-2\ln\alpha_i^{(1)}(\omega)}\sin(2\pi\alpha_i^{(2)}(\omega)),$$

$$\xi_i^{(2)}(\omega) = a + \sigma\sqrt{-2\ln\alpha_i^{(1)}(\omega)}\cos(2\pi\alpha_i^{(2)}(\omega)), i = \overline{1, m}.$$

Approximate method of Gaussian white noise modeling is based on the use of central sweeping limit theorem, corollary of which in this case can be expressed as: independent random variables $\alpha_1(\omega), \alpha_2(\omega), ..., \alpha_m(\omega)$ are distributed identically (uniformly in the interval [0,1]) with the mathematical expectation $\mathbf{M}\alpha_m(\omega) = \frac{1}{2}$ and variance $\mathbf{D}\alpha_m(\omega) = \frac{1}{12}$, (conveniently to choose $n = 12$), so for sufficiently large value m the random variable $\xi_n(\omega) = \sqrt{\frac{12}{n}}\sum_{k=1}^{n}(\alpha_k(\omega) - \frac{1}{2})$ has approximately normal distribution $N(0,1)$. Sufficient for most practical applications proximity of distribution $\xi_n(\omega)$ to $N(0,1)$ is achieved already when $n > 10$.

Simulation of stochastic processes with independent increments. Algorithm of simulation of random sequences with independent increments follows from its definition. We model a sequence of independent random variables $\xi_i(\omega)$, $i = \overline{1, m}$ (increments) with a given distribution (methods described in the previous two paragraphs), and then we get the required sequence $\eta_i(\omega)$, $i = \overline{1, m}$ with independent increments.

With use of information systems there can be built models and some processes with continuous time, those that are changing only by jumps. Simulation modeling of such processes is reduced to the sequence of points during the simulation time of jumps appearance modeling and to the jumps as itself magnitude simulation.

The simplest example is a stochastic process with independent increments, which varies only by jumps in nonrandom time moments. Here sequence of points in time $0 < \tau_1 < \tau_2 < ... < \tau_k < ...$ of jumps occurrence is given (determined), so that we have only simulate a sequence of independent increments $\xi_1(\omega)$, $\xi_2(\omega)$, $\xi_3(\omega)$, ... with a predetermined distribution.

Modeling of random time points sequence $0 < \tau_1 < \tau_2 < ... < \tau_{k-1} < \tau_k < ...$ at which take place jumps of homogeneous Poisson process is based on its property that magnitudes $\Delta\tau_1 = \tau_1$, $\Delta\tau_2 = \tau_2 - \tau_1$, $\Delta\tau_3 = \tau_3 - \tau_2$ and $\Delta\tau_k = \tau_k - \tau_{k-1}$ time intervals between jumps are independent random variables with a single exponential distribution and the parameter λ. Magnitude of each homogeneous Poisson process $\pi(\omega, t)$, $t \in [0, \infty)$ jump equals one. Therefore, its modeling algorithm will look like this: we simulate a sequence of independent random variables $\Delta\tau_1, \Delta\tau_2, ..., \Delta\tau_k, ...$ of identical exponential distribution with the parameter λ; form a sequence of points in time $\tau_k = \tau_{k-1} + \Delta\tau_k$, $k = 1, 2, 3, ...$, in which there are jumps ($\tau_0 = 0$); the process $\pi(\omega, t)$ and we obtain so: $\pi(\omega,0) = 0, \pi(\omega,t) = \sum_{\tau<t} 1, t > 0$.

To build a model of a generalized homogeneous Poisson process it should be modeled by means of the above mentioned method a simple homogeneous Poisson process – an independent sequence of increments $\xi_1(\omega)$, $\xi_2(\omega)$, $\xi_3(\omega)$, ... with the specified distribution.

Simulation of Markov processes. Markov process of *m*-st order is completely determined by the first $m + 1$ distribution functions. Therefore, the method of modeling using conditional distribution function gives the exact algorithm of Markov's for the *m*-st order sequence simulation at the predetermined first $m + 1$ functions.

Markov's sequence $\xi_i(\omega)$, $i = \overline{i, m}$ (of first order), is completely determined by the distribution function $F(x_0; 0)$ of the "initial" state $\xi_1(\omega)$ and by the function of distribution of one-step transitions $F(y; t|x; t-1)$, $t = 2, 3, ..., m$. If these distribution functions are known, the simulation of Markov sequences $\xi_i(\omega)$, $i = \overline{1, m}$ is made as it shown below.

First, we should model the random variable $\xi_1(\omega)$ (here we get realization y_1) with the distribution function $F(x_1; 1)$, after that – random variable $\xi_2(\omega)$, (realization y_2) with distribution function $F(y; 2|y_1; 1)$ (y_1 – fixed), then – the random variables $\xi_3(\omega)$, $\xi_4(\omega)$, $\xi_5(\omega)$, ... (realizations – y_3, y_4, y_5, ...), respectively, with the distribution functions $F(y; 3|y_1; 2)$, $F(y; 4|y_1; 3)$, $F(y; 5|y_1; 4)$ etc. If $\xi_i(\omega)$ is no interrupted meaning Markov sequence, then it is entirely specified by distribution density function $f x_0; 0)$ of the "initial" state $\xi_i(\omega)$ and by distribution density of one-step transitions $f(y; t|x; t-1)$. Obviously, the core algorithm of the simulation modeling in this case is not changed (for simulation modeling of random variables $\xi_1(\omega)$, $\xi_2(\omega)$, $\xi_3(\omega)$, ... with distribution density, respectively $f(x_1, 1)$, $f(y; 2|y_0; 1)$, $p(y; 3|y_1\ 2)$, $p(y; 4|y_2; 3)$.

2.6. Characteristics of information systems reliability as of the hardware-software system

Nowadays, research methodology regarding complex technical systems reliability, including informational are based on the study of reliability of hardware-software systems that consist of:

– hardware facilities constructed from the corresponding elements, components, modules, sub-systems of varying complexity and also of diverse nature physical functioning (acoustics, nuclear physics, optics, mechanics, radio physics, electronics, geophysics, hydromechanics etc.) for a wide range of subject areas use (machinery, transport, energy, telecommunication systems etc.);
– software package, or rather an aggregate of:
  - mathematical software in the form of mathematical models, methods and algorithms within those the hardware-software systems perform the required tasks in accordance with intended purposes;
  - ensuring in the forms of databases enabled with controlling functions, the file structures provided with management systems, the conditionally-permanent constants or variable data, the protection devices against unauthorized access (information security device), the data input control devices and other devices that determine the formation (measurement), training, processing of the various subsystems and hardware-software systems operation control in general (position lights, sensors and sensor devices signals, control signals etc.);
  - software that implements the mathematical provision of hardware-software systems and consists of a software system and functional (application) software.

Programming hardware-software systems complex is also called "soft hardware". Failures of "software" and these errors at the operation of complex software are of no difference from the failures of hardware complex. Therefore, the most reasonable approach is when "soft hardware" reliability is estimated by the degree of influence on the reliability characteristics of the whole hardware-software systems complex. It is very important that the failure of hardware instruments and software complex are essentially interrelated events. Examples of such interactions can be found in a significant amount. But due to the complexity of this task accomplishing, today's problems of reliability identification characteristics in the hardware-software systems have to be done according the following scheme:
– evaluation of software-hardware complex tools characteristics has to be determined separately for each of the complexes as for independent events,
– principal characteristics of hardware-software system have to be determined by combining both characteristics of hardware circuit means and soft complex as of independent proceedings.

It should be also taken into account the following features of reliability characteristics of the hardware-software complex. Namely to characterize the reliability of hardware devices it is important to insure the following items:
– collected large calculation database, experimentally verified by testing and operation in similar technical devices, in the systems characterizing reliability along a considerable period of time (up to several tens of years),
– for grounding the characteristics of hardware means reliability it can be used the statistical data processing method by means of averaging the data obtained at operation and service tests on an appropriate number of similar devices,
– on the time interval the hardware resources operation are "aging" system.

To characterize the reliability of software system it must be taken into account the following:

- to identify the software errors there cannot be used the method of statistical averaging, because apposite copies of the software reproduce the same error,
- during testing, commissioning and operation the number of software errors can be detected and then diminished, suggesting to the fact about operation of software system as of "revitalized" system,
- software system has no timing period of wear and in practice it virtually does not contain manufacturing errors (of copying).

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3. Factors affecting the information systems reliability and failures

This section is related to the analysis of factors, which encompass effects on the performance reliability of information systems. The materials reflect significant results gained during the last decades of the twentieth and early twenty-first centuries, experience with technical systems of varying complexity in almost all domains of scientific and technological sectors of economy. These results can be used at all stages of the information systems life cycle both in the study of its reliability characteristics.

Below are presented materials regarding classification of failures and also some illustrative examples of failures formation in information systems [1–7].

3.1. General classification of factors

During the analysis of modern information systems functioning as of hardware-software systems it is taken into account the influence of a large number of factors. This section describes the major factors that affect the operation of such systems.

The major stage factors influencing the systems reliability can be divided into three groups [1, 4]:

- at project,
- at production,
- at operation,

these emerge at various stages of a system life cycle.

The project stage includes factors the action of which at the design and construction stage determines circumstances of subsequent hardware and software failures. These factors include the selection of element types (chips base), selection of principles, electrical, hydraulic, structural, logical and other schemes, operational modes of elements choice, adoption of designing automatization, selection of programming techniques, manufacturing of parts and modules; methodology of manufacturing processes; system functioning software development.

Production stage includes factors arising during the production of the systems and affecting theirs reliability. These factors include the quality control of materials and items received from suppliers, the incoming inspection of components at manufacture, preparation and organization of production processes, organization of the set-up process, adjustment of equipment and processes, the.

Operational stage includes the external affecting factors and activities that carried out at equipment maintenance. Depending on the nature of the system all possible external factors are divided into six groups: mechanical, climatic and other natural, radiation, thermal, electromagnetic fields, specific external factors, particularly – aggressive environs.

To the maintenance regulation activities belong regulation, prophylactic works including scheduled preventive maintenance, the training, the testing, preoperational testing, performance monitoring, collection and analysis of data related failures.

It can be characterized now in detail the major factors affecting the reliability of information systems as of a hardware-software system, which include climatic, electrical, electromagnetic radiation, shock, vibration, and other factors that affect the software reliability.

3.2. Climatic factors

Climatic conditions influence on the change of work characteristics and parameters of information systems mainly due to the environ temperature, pressure and humidity changes.

Technical, including informational, systems operate in diverse temperature surroundings. Seasonal and diurnal variations in temperature T [°C] in various climatic zones are given in Table 3.1.

Table 3.1

Seasonal and diurnal temperature T [°C] variations in diverse climatic zones

Climatic zone	Seasonal fluctuations T [°C]	Daily fluctuations T [°C]
Desert	from –20 to +50	40
The temperate zone	from –20 to +40	25
Arctic zone	from –50 to +35	20

These temperature changes also affect the equipment characteristics during its control, storage and service.

3.2.1. Characteristics of climatic factors influence

Among the climatic factors are the following: pressure, ambient temperature, humidity of air and other gases, precipitations, dust and sand, solar radiation (insolation), the flow of air and other gases, corrosive medium with active ingredients including biological milieu and ice-soil surroundings.

Effects of heat and cold. The action of these factors is determined with the type of installation mode (on the ground in residential areas, in a vehicle, in a ship, in an aircraft), climatic category of equipment performance, regarding the distance from the external thermal actions.

There are three types of thermal action: continuous, periodic, and aperiodic. The first type of action occurs when operating equipment is installed in residential areas. At stationary conditions thermal influence the damage emerges mainly as a result of the operation at temperature values exceeding the maximum allowable. The largest part of ground equipment, ship and aircraft is affected by periodic thermal influence. It occurs mostly at intermittent switching under load, at sharp fluctuations in operating conditions (deep immersion, at space flights conditions, at radiation, at takeoff, flight, landing), at daily changes in ambient temperature. Temperature jumps in ground equipment can reach 60°C, for the aviation equipment up to 80°C. Aperiodic thermal action is observed in the process of rocketry equipment operation and at spacecrafts – at launch and at entering the atmosphere. The result of heat shock can be a sudden failure of equipment. High rate of temperature change (thermal shocks) leads to the rapid changes (expansion or compression) in the sizes of materials. At elevated temperatures the filling materials soften and materials that interact with them expand. At supercooling, in contrary, potting materials are compressed at their contacts with the metal start cracking; at the output of electric appliances are created volumes not completely filled with materials and that increase the likelihood of electrical discharge.

Temperature greatly affects the electrical parameters of the electrical circuit equipment. Changing the temperature alter the geometric dimensions, relative positions of the parts of constructional and structure elements. This causes a change in the capacitance, inductance and electrical resistance, eventually lead to a change in its output parameters and characteristics.

Especially dangerous are temperature transitions "through the zero" (from positive to negative values) because the moisture presenting in the gaps and cracks freezes, thus increasing its volume, reducing gaps.

Elevated temperature degrades insulating properties of fillers, straightness and mechanical properties of some polymers, leading to deformation of parts. Variation in the characteristics and parameters values at temperature change can be reversible or irreversible.

Effects of moisture. Elevated humidity can cause changes in the superficial and volumetric insulation resistance, reducing the electric strength of the material; changing the physical properties of materials, theirs density, melting points; resizing and warping individual parts, accelerates aging, oxidation and corrosion of materials, reducing resistance to damage by fungus, increasing the intensity of wear of coatings, insulation, parts etc. High humidity accelerates the rate of corrosion processes in time, for example, for oxide film formation takes place the following equation:

$$\frac{dy(t)}{dt} = C_p(t)k_p(t)\exp\left(\frac{-E_k(t)}{RT}\right),$$

where:

$y(t)$ – the thickness of the oxide film,
$C_p(t)$ – concentration of the reactant (water, oxygen, aggressive mediums),
$E_K(t)$ – activation energy of the corrosion process,
R – the universal gas constant,
T – temperature [°C],
k_p – the rate of corrosion processes.

The rate of corrosion processes and the development of cracks do not depend only on the humidity and temperature, but also on the quality of materials, construction equipment, manufacturing technology and corrosion protection means. Here are some examples.

1. **Copper** – one of the most important materials in electrical engineering and electronics – it has good resistance against corrosion. Under the influence of oxygen, carbon dioxide and moisture of the air on the surface of solid copper forms a protective layer of copper carbonate. Typically for winding of inductors is used enameled copper wire. In low-quality enamel coating often occur cracks. Through these cracks the electrolyte (water) can penetrate into contact with metallic copper, which due to current flow, becomes an electrode with a distinct polarity and in case of the anodic load metal rapidly passes into solution. Experimentally it was established that the service life of the coils at 75% relative humidity make about three years, and at the relative humidity of 100% – only 5 days (at 45°C). It can be noted that in Kiev and its environs an average relative humidity almost all year rounds for more than 80% and in July and September – more than 85%.

2. **Soldering.** Soldering of components is made with tin-lead alloy. At elevated humidity and temperature alloys containing less than 60% tin corrode quickly. At low temperatures, pure tin or tin alloys with aluminum or zinc are degraded into an amorphous modification. Content more than 50% of lead in the alloy prevents this phenomenon, the so-called tin plague.

Humidity most strongly influences the parameters of electronic equipment. To the growth of humidity significantly contribute precipitation and sudden changes in temperature. At the temperature change in equipment occurs a partial condensation of humidity. The condensed moisture fills cracks and leaks in the insulators and coatings, deteriorating its electroinsulating properties. The presence of moisture leads to the change of superficial insulation resistance. As a result, there occur deviations in the electric parameters due to the emergence of current leakage, growth of electrical circuit capacity and reducing the inductors quality factor.

Effects of moisture on the equipment are mostly irreversible.

The action of sunlight. At operating of equipment outdoors its surface is exposed to direct sunlight. Solar radiation is the major source of heat. It greatly depends on climatic region, atmospheric circulation and characteristics of the underlying surface. Thus, in the sunny areas (Central Asia) the average integrated flux density of the direct – S and summary – Q solar radiation at 12:30 A.M. regardless to the clouding had reached in June, $S = 719$ W/m^2, $Q = 900$ W/m^2; in September $S = 824$ W/m^2, $Q = 810$ W/m^2. The same month in the north Russia these characteristics were: June, $S = 356$ W/m^2, $Q = 537$ W/m^2, September, $S = 377$ W/m^2, $Q = 349$ W/m^2. The occurrence of maximum positive temperature is directly related to the level of solar radiation.

Effects of solar radiation on the variety of equipment is determined by the length of the electromagnetic waves that reach its surface and radiation balance distribution, taking into account the receipt and outgo of solar radiation energy. The ultraviolet waves part of the spectrum accounts for about 9% of solar radiation energy, the visible part of the spectrum – nearly 41%, the infrared waves – approximately 50%. The presence of clouds reduces the amount of solar energy reaching the Earth by about 75% compared to bright days. Thus, measurement of surface heat flux radiation density at various total cloud coverage, which was held in Odessa in the summer months, has shown the following: at the height of the Sun of 44.9° the flow varies from 784 W/m^2 during cloudless weather to 259 W/m^2 at the thick cloud coverage and at the height of the Sun 9° – respectively, from 126 W/m^2 to 42 W/m^2.

Integral heat flux is a function of an altitude, at altitude of 15 km it makes 1,125 W/m^2, including ultraviolet part – 42 W/m^2, and at an altitude of more than 15 km – 1,380 W/m^2 and 100 W/m^2 respectively.

The presence of dust and water vapor in the air significantly reduces the heat flux of solar radiation. The most severe effects on materials and equipment are provided by the sunlight falling perpendicular to the surface. Land is a poor conductor of heat, so the solar radiation affects mostly the temperature of the upper surface layer. Here is an example to illustrate this statement: while the morning temperature at the surface of the asphalt and at the ground slightly away from the asphalt and at 30 and 120 cm above the ground was 30°C, then at 15:00 the temperature at the surface of the asphalt grows up to 52°C and at 30 and 120 cm above up to 43°C and 40°C respectively, while at the ground away from the asphalt – only up to 34°C.

The major factor of solar radiation action on the surface of an appliance is a heating of device apparatus casing and the consequent rise of temperature inside the appliance. Heat absorbed by the upper cover lid is emitted into the device and reaches the bottom surface of the casing, which then gives off the heat to the ground. After reaching thermal equilibrium there can be calculated the extent of heating of a black case jacket with the sunlight for different geographical latitudes. Calculations show that the temperature at the lid and bottom of a casing at 4° latitude they can reach 81°C and 64°C respectively, and at latitude of 60° some 64°C and 52°C. A color of painting of a device casing into appropriate colors can reduce its heating, compared to the blackbody surface onto 10–15°C.

Material damages by sunlight can be divided into photolytic and photooxidative. Photolytic processes occur at such radiation frequency when the photon energy is sufficient to break up the intermolecular bonds. The simultaneous action of oxygen and moisture create via photooxidative processes a greater damage effect. Ultraviolet irradiation activates the metals surfaces and can eventually lead to corrosion.

The energy of ultraviolet irradiation is strong enough to break the chemical bonds between carbon and hydrogen. Consequently, polyethylene, ethyl cellulose, lacquers and paints become brittle and lose strength, which eventually leads to the failure of a device.

Pressure. Operating at Earth surface technical devices should maintain reliability and the specified performance at changing air pressure in the range from 550 to 1,080 hPa. The upper limit corresponds to the pressure at sea level, the lower –to the pressure, designed for maximum height (4.6 km), at which may proceed the use, storage and transportation of technical devices. With increase the altitude decreases dielectric strength of air, so that it is needed to reduce the allowable values of breakdown voltage in the electrically insulated items. The coefficient of relative electric strength in air gaps relative to the electric strength at 1 km is 0.9 at altitude 2 km; 0.62 at altitude 5 km; 0.35 at altitude 10 km and 0.10 – at altitude 20 km.

Effect of atmospheric pressure is mainly manifested at its influence on the hardware installed in non-hermetic compartments (blocks) of airplanes. The influence of atmospheric pressure depends on the altitude of the airplane. With the change in pressure changes the insulating properties of air and the dielectric constant, which subsequently leads to the change in electrical capacity of air-filled capacitors as well as in the characteristics of other elements, in which air is used as an insulator. With decrease of pressure deteriorate the cooling surroundings of elements, as well as reduces the heat transfer efficiency due to convection. This leads to the overheating of elements, especially at elevated altitudes.

Effects of pressure on the equipment characteristics can be reversible and irreversible. In many cases dominates the reversible process. For example, with the airplane mounting to an altitude where the pressure decreases sharply it can be observed arcing, breakdown of equipment elements, changing frequency of klystrons generation etc. With decrease of height the settings of equipment restored.

Effects of sand and dust. Action of sand and dust degrade the appearance of the equipment. Dust and sand get into lubricants and stick to the surface of protection layers. As a result, there increased binding or "dead fly" in the bearings (printers, drivers etc.). A thin layer of soot absorbs gases, such as sulphurous, that act on the equipment destructively. Another type dust, which is caked, contributes to the accumulation of moisture and reduces resistance of insulation. Deposition of dust facilitates the emergence of leakage currents in the solid insulating materials. Characteristic damage which is caused by dust is a bad operation of switching contacts. About 40% of all equipment damage is due to not good enough functioning of contacts.

Effects of biological factors. Most dangerous among biological factors is the effect of mold on the insulation materials based on organic (glass press pan, textolite, vulcanized fiber etc.). Under the action of molds there decreases mechanical strength of materials and devices containing them. Mould fungi often grow in the devices that are stored in dusty areas. In the mold damaged electronic equipment which has the printing, registration and other devices it becomes possible a malfunction of electrical connections. Effects of organic acids secreted by mold accelerate contacts corrosion. The damage by a mold often begins at cotton braid cord cable connections and then it spreads onto the wire with silk lacquer insulation.

The biological surrounding most strongly influences the electronic equipment of aircraft during storage, especially outside the hangars, at airfields. Warm and humid ambiance leads to the mold or fungal covering of equipment.

In some cases, on the equipment at storage may also affect insects, such as termites, red ants and others. Among most dangerous rodents are rats, mice, squirrels etc., damaging the insulation. The biological medium often leads to irreversible changes in the electronic equipment characteristics.

The action of wind and ice. On the equipment located outdoors act wind and ice. At icing is increased size and weight of equipment, which leads to the aerodynamics and mechanical stress growth. Assessment the influence of ice and wind process, which is caused by random meteorological factors, can be made according probabilistic and statistical methods. The study of statistical relationships between the equivalent icing thickness and maximum wind speeds have shown that they are insignificant and the correlation coefficients are close to zero. The distributions of these random variables are well described by the laws of distribution such as by Weibull.

Classification by climatic regions. Taking into account the external factors affecting the reliability requirements and system operation conditions normalizing there were differentiated macroclimatic areas and systems – namely they were divided onto climatic regions and types of premises for the hardware operation.

There are four microclimatic zones: cold, moderate, hot and dry tropical. There are moderately warm, humid (Lviv, Ternopil), moderately warm with wet winters (Odessa, Kherson, Nikolaev).

Classification of climatic equipment performance according the type of premises. It were distinguished 5 categories of systems for operation in premises of different types: 1 – the systems designed to work outdoors, on open air, 2 – the systems designed to operate indoors, 3 – systems designed for operation in enclosed spaces with natural ventilation, 4 – the systems designed to operate in areas with artificially regulated climatic conditions, and 5 – the systems designed to operate in areas with high humidity (e.g., unventilated underground areas).

Climatic design of equipment classification by the type of climatic regions. Distinguished are ten classes of devices by the types of climatic regions: L, XL, PHL – for climatic regions with temperate, cold, and moderately cold climates, T, TV – climatic regions of tropical and humid tropical average temperatures, O – for all regions, M – for the ships working in areas with moderate to moderately cold climates, TM – for ships operating in areas with tropical climates, Y – for all areas; OM – for unrestricted navigation areas.

3.2.2. Hardware protecting from climatic influences

Security of equipment can be done in two modes: selection of high quality materials and components and the use of special means of protection. Relation between them is determined by the mass-size device characteristics, with the requirements for reliability, performance cost and other factors. At choosing of protection it can be used highly hygroscopic materials that tend to concentrate moisture. Therefore its surface must be as airtight as possible. These requirements meet mostly *thermoplastic materials.*

The majority of faults and failures at the operation of equipment occur at *the contacts of different metals and metals with plastics*. Therefore, a reliable method of its protection is a utilizing of suitable and exclusion of improper contacts. In the common manuals for equipment manufacture normally are specified acceptable and unacceptable contacts of various materials and their alloys in medium, tough and very demanding environs.

From corrosion contacts are protected with electrical insulation (electrical disconnection) of contacting metals; by electrochemical methods (cathode protection and protective anodic coating); excluding or reducing the aggressive action of corrosive media (introduction of inhibitors, desalination, deoxygenating). Contacts should be positioned where operating conditions are less aggressive, where absents both effect of electrolyte and periodic wetting.

Electrochemical protection against contact corrosion is used in cases when it is possible to carry out electrical separation of the contacting metals with the help of active metals protectors (magnesium alloys, zinc, steel, aluminum alloys and zinc) attached to the contact pair.

Equipment protection from combination of moisture and heat is one of the major measures for reliability ensuring at the equipment designing stage. Methods of such protection are varied. To attain a protection level close to absolute are used various hermetic devices housings. Methods of protection of metallic elements are provided by exclusion of corrosion, and one of the simplest methods is grinding and polishing of surfaces. The same goal is achieved by blocking the chemical reaction between metal and media, using anodic coating, electrochemical potential of which is lower than of basic metal (e.g. for steel parts is used the three-layer coating: copper-nickel-chromium) also in use are lacquer paint coatings. To coat electronic components widely used are epoxy and silicone varnishes and enamels. They possess high electroinsulating properties, are moisture resistant and can operate at elevated temperatures. In radio engineering practice in use is also a number of methods for moisture protection: surface hydrophobization; soaking with insulating materials, impregnation with resin and epoxy compounding and vacuum hermetization.

One of the major methods to protect equipment from damage by mold is a chemical method – the usage of special toxic compounds such as fungicides, i.e. substances that kill mold and fungistatic substances to prevent mold growth. Inorganic fungicides are salts of copper, mercury, zinc, and chromium. Organic fungicides are mostly chlorinated phenol and nitrophenol. Organometallic fungicides are compounds of copper, zinc, mercury.

3.3. Electrical, electromagnetic and radiation factors

Electrical modes of operation can change characteristics of electronic equipment due to the changes in supply voltages, in current loads, in electrical input signals changing, and so on. Electrical equipment running modes at the equipment operation change in a relatively large range.

At operating of electronic equipment may emerge fluctuations in the supply voltage, up to ± 10–15%, as well as changing the shape of the variable voltage curve – with clear factor up to 15%. Levels of signal input of receivers may vary in tens, hundreds or more times. The dependence of the apparatus parameters from change of supply voltages and signal levels is determined by the presence of nonlinear elements in the equipment. Changes in electric regimes, as a rule, lead to reversible changes in the equipment characteristics.

Electromagnetic interference into operational conditions gives rise to fluctuations in the electronic equipment characteristics.

The sources of electromagnetic fields are various industrial electrical installations, lightings, radio stations radiation, electrostatic discharges that occur at electrisation during air friction against lining of aircraft etc.

Particularly strong effect of electromagnetic disturbances is manifested at their direct influence on the input of amplifying devices. It changes the amplifying gain and distorts the received signals.

The influence of electromagnetic interference usually results into reversible changes in the electronic devices characteristics.

Nuclear radiation – one of the worst acting factors that affect the parameters of electronic equipment. Changes of equipment characteristics largely depend on the type of radiation (irradiation by neutrons or gamma rays) and on the intensively of irradiation.

At the action of nuclear radiation sharply decreases insulation resistance. In electrolytic capacitors exposed to radiation changes the structure of electrolyte.

At irradiation with fast neutrons inside germanium and silicon diodes and triodes, photo resistors, thermistors etc. occurs displacement of atoms in the crystal lattice. Resistors with high resistance (over 108 ohms) at irradiation fundamentally change their characteristics.

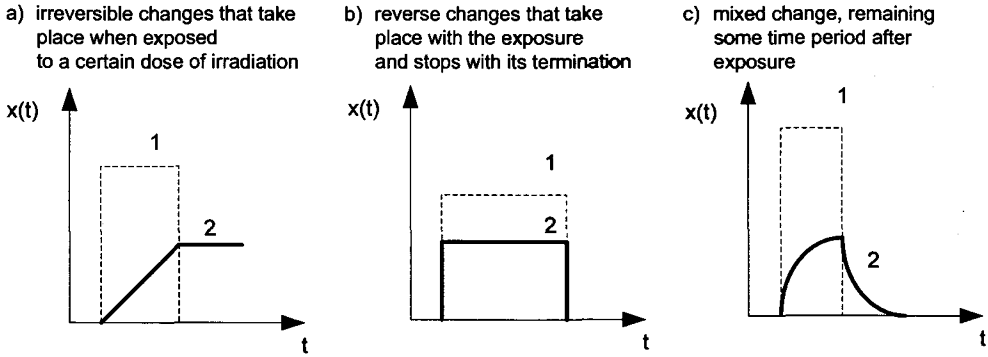

Fig. 3.1. Diagrams (a–c) of materials characteristics change x(t) over time when exposed to nuclear radiation: 1 – pulse irradiation, 2 – changes in the substances

Changes in materials $x(t)$ over time when exposed to nuclear radiation occur in three modes:

- irreversible changes that take place when exposed to a certain dose of irradiation (Fig. 3.1a),
- reverse changes that take place with the exposure and stops with its termination (Fig. 3.1b),
- mixed change, remaining some time period after exposure (Fig. 3.1c).

Often all three types of change take place simultaneously.

3.4. Shock-vibration factors

Mechanical effects are caused by shocks and vibrations that occur during the operation of equipment, the sources of mechanical stress can be fans, mechanical switches, pulse rate monitors and other mechanical and electromechanical equipment. The major source of vibration during a flight is an aircraft engine.

In aircrafts occur vibrations with a frequency from units of Hz up to several kHz. The highest change of settings in electronic equipment emerges at resonance conditions in blocks, in electro vacuum elements, in semiconductor devices and micromodules. In practice, the resonance frequencies of the blocks are in the range of 5–20 Hz, at elements of electronic tubes – 0.3–1.5 kHz, at elements of semiconductor devices and micromodules – unites of kHz. At the resonance emergence on electronic equipment construction can affect overloading 15–20 g.

Effect of mechanical stress leads to a formation of accidental variable contacts, to change of geometrical dimensions and relative positioning of components which causes deviations in capacitance and inductance of an installation.

In most cases mechanical effects lead to the reversible changes.

Vibration loads are divided into random and nonrandom. Accidental loads, in turn, are periodic and non-periodic and random loads – stationary or non-stationary.

3.4.1. Characteristics of vibration factors

The real vibrations are those which can be described by the classical functions: harmonic, quasiharmonic with continuous change in frequency within a broadband or narrowband random process. Quasiharmonic vibration with a continuous change in frequency occurs during acceleration and slowing down the mechanisms with rotating parts. Broadband random vibration is an idealization of random vibration which affects the equipment at actual operation. Narrowband random vibration occurs at vibrations of elastic systems under the influence of broadband vibration.

Shock loads are divided into non-random (periodic and nonperiodic) and random. Periodic shock satisfies condition $x(t) = x(t + kT)$, $k = 1, 2, 3, \ldots$, T – repetition period.

By the form shocks can be rectangular, sinusoidal, cosinusoidal, saw-tooth alike and complex form shock loads. The above mentioned forms of influence are determined by the time dependence of acceleration.

$$x_1(t) = x_0;\; x_2(t) = x_0 \sin\left(\frac{\pi t}{\tau}\right);\; x_3(t) = x_0\left(1 - \cos\left(\frac{2\pi t}{\tau}\right)\right);\; x_4(t) = \frac{x_0 t}{\tau},$$

where:

x_0 – the peak value of acceleration,

τ – the time length of impact.

Characteristics of shock-vibration factor are determined at taking into account equipment operating conditions classification. According such criterions all diversity of technical equipment can be divided into five classes: ground equipment, marine (ship) technique, airborne aviation electronics and rocketry and space technology. The levels of shock-vibration loads depend on the type of carrier equipment and the location of its accommodation on a carrier. All objects of ground equipment, depending on the operating conditions, can be divided into stationary, moving and those that are vehicle borne. Moving objects can be wheeled or tracked. The causes of equipment vibration on a mobile carrier are shaky gadgets in construction, vibration of engine, road surface roughness.

Vibration acceleration $m \cdot s^{-2}$ can vary from 10–20 $m \cdot s^{-2}$ at the springing vibrations at driving on the road with a smooth surface at a speed of 90–120 km/h up to 300–400 $m \cdot s^{-2}$ at non springed vibrations when driving on cobbler-stone roads at a speed of 45–75 km/h. Mechanical shocks have the following characteristics: repeated blows actions give peak shock acceleration up to 1,500 $m \cdot s^{-2}$ with action duration 2–5 ms, a single action shocks have peak acceleration up to 30,000 $m \cdot s^{-2}$, duration up to 5 ms. Ground equipment that is placed on the trucks or on caterpillar type tractors experience acceleration at strikes up to 1,000 $m \cdot s^{-2}$, located on the panzers – 1,500 $m \cdot s^{-2}$.

At designing of equipment which is placed on the earth moving vehicle is used the classification of the International Electrotechnical Commission by Mechanical Conditions (Tab. 3.2).

In marine engineering equipment on ships of small tonnage are carried on vibration frequencies up to 2,000 Hz, amplitude of 1–2.5 mm and acceleration at collisions up to 500 $m \cdot s^{-2}$. The ships of large tonnage generate vibration up to 60 Hz, amplitude 0.5–2.5 mm and at collisions acceleration up to 1,500 $m \cdot s^{-2}$.

Table 3.2
Groups of mechanical requirements of vehicles classification and levels

External influencing factors	Class		
	5M1	5M2	5M3
Sinysoidal vibration:	1.5	3.3	7.5
– amplitude of displacement [mm]	5	10, 15	20, 40
– amplitude of acceleration	2–9	2–9	2–8
– frequency range [Hz]	9–200	9–200, 200–500	8–200, 200–500
Stationary random vibration:	0.3, 0.1	1, 0.3	3, 1
– density of the acceleration [m · s^{-2}]	10–200	10–200	10–200
– frequency range [Hz]	200–500	200–500	200–500
Non-stationary random vibration, including shock			
– impact range of deviation type 1 peak acceleration [m · s^{-2}]	50	100	300
– impact range of deviation type 2 peak acceleration [m · s^{-2}]	–	300	100

During the facilities development and manufacturing are to be assigned the so-called "normal" operating conditions:

– temperature +25 ± 10°C,
– relative humidity 60 ± 20%,
– relative mechanical loads etc.

In the apparatus of aviation equipment take place vibration frequencies up to 200 Hz with amplitude about 1 mm at aircrafts with piston engine, 500 Hz and 0.5 mm at turboprop aircraft, up to 2,000 Hz and 0,025 mm in the jets. Shock accelerations (up to 500 m · s^{-2}) are about the same for all types of aircraft. During takeoff and landing the apparatus encompasses considerable overload. Thus, the vibrations in the jets are created by sound frequency vibrations caused by jet flow and fuel combustion turbulence, having the following characteristics: 500–10,000 Hz frequency, amplitude at frequencies 500 Hz up to 0,025 mm. The major source of vibration at items of missile technology is the work of a rocket engine, control system and aerodynamic effects. Rocket engines operating on liquid fuel create a vibration with a frequency of several hundred Hz and acceleration up to 500 m · s^{-2}. Stronger vibration is exposed to equipment, which is located nearer the engine. At the moment of launch and the stages separation the shock levels reach 5,000 m · s^{-2}.

3.4.2. The effects of mechanical stresses

There are two mechanisms of mechanical loads actions influencing the equipment reliability. The mechanism of first type is characterized by the absence of disturbances accumulation. During any time a definite option is a function of the current state of the equipment and it is independent of the preceding background of operation. The major feature of the second type mechanism is the existence of disturbances effects accumulation, such as an accumulation of fatigue damage in the assembly of equipment.

At assessing the first type mechanical stress effects are used methods for no inertial functional transformation of random processes.

At assessing the effects of second type mechanical stress, probability of equipment failure is determined as a probability of fatigue breakage caused by periodic variable loads with the known parameters or as the complex dependences of the stress in the materials on time. At the same time there actively used the results of materials fatigue tests.

3.4.3. Protecting equipment from exposure to mechanical stress

For the protection against mechanical stress are widely used special vibroinsulation devices – vibroinsulators, installed between the appliance and the vibrating support. By the nature of protection from the applied external loads are distinguished active and passive insulations.

If a unit itself is the source of fluctuations, from which it is needed to isolate a supporting base, then it is defined as an active isolation. If it is desirable to protect the device from vibrating support – it is passive isolation. Means of isolation in both cases are the same, but the requirements for vibroinsulations are different, depending of the nature of the applied external loads and the kind of enforced oscillations.

Vibration protection measures during operation and during transportation are different. At transportation the equipment can be subjected to dynamic loads. In this case, the vibroinsulators are needed to provide protection of equipment from accidental bumps and jolts of large amplitude. In such case vibroinsulator must meet serious demands to weaken accidental bumps and shocks of large amplitude. Attenuation of shock loads as of sudden impulses, in which develops acceleration values to tens of thousands of milliseconds in the minus second degree is achieved by using of specialized vibroinsulators. At vibroinsulator designing or selecting it must be taken into account the fact that more deforming is vibroinsulator (vibroinsulator softer), less acceleration shock acquires the apparatus.

The effectiveness of vibroisolation depends on the damping factor and on the ratio of excitatory and natural vibration frequencies. Equipment construction may have its own oscillations frequency, which is different from the frequency of excitatory shock.

3.5. Factors affecting the reliability of software

Information systems that consist of software- hardware facilities use various functional software systems that can be classified as software systems with long duration of use. The magnitude of functional capacity of software system may vary over a wide range (from a few thousand to several million instructions). It allows modification, duplication, can be documented as industrial products and therefore it is the correspondent software.

The life cycle of functionally software systems, including the modifications may reach 10–20 years, therefore these systems are considered as highly reliable. Namely the cycle consists of four major stages: system analysis and pre-defined preparation, design (development), operation and maintenance. To the last two stages belong 70–90% of the life cycles time. During the system analysis and at the pre-defined preparation are determined the purpose and basic functional performances of the software system, evaluated the effectiveness of its possible applications, established requirements for reliability and forms a concretized technical specification for its development.

The major factors that determine the occurrence of errors in software development and affect the reliability of the functional complex software are as following.

1. The scale and complexity of the systems of automated processing and management as a result of the diversity of objectives and management criteria, the influence of the feedback loop in the control circuit onto dynamic performance, the complexity of temporal characteristics, the dynamics of changes of some data measurement accuracy, large volumes of treated and transmitted information, versatility and variety of modes;
2. Inability of confident prediction of calculations accuracy, time of reaction on the change from the outside, the degree of influence of surrounded (especially informational) milieu on the results of functional software operation;
3. The intricacy of specialists of various professions communication involved in the development of common requirements and their interpretations of special requirements regarding informational, mathematical and programming media.

Years of experience of various groups of highly skilled software developers (software) for hardware-software systems (information systems) has shown that if there has been made any kind of error at this stage then it will significantly reduce the functional reliability of a software system. Errors at the development of software requirements and its structure selection are major faults that possess considerable persistence at all stages of the life cycle and also engages a property to change largely the structure of the software at the trials to remove these faults.

At the design phase of software it could be selected the following steps:

- development and debugging of algorithms,
- implementation of algorithms in a programming language,
- debugging of modules, blocks of software and system functional software as a whole (integrated debugging),
- creating documentation for software.

The major factors that determine the correctness of programs, and therefore, the level of reliability of software design are as following.

1. *Technology of development, including programming technology.* At technologies variants selecting should prefer options for the enforcement of various simulation (computational) experiments for debugging software still on the stage of algorithms development. Significant influence on the accuracy of programming have methodological factors that are provided by design technology, the level of mastering and actual applicability of the software team at the designing process. At algorithms and mathematical software developing it is important to have the object management model. This allows conducting active computation modeling experiments for debugging software even before creating the actual control algorithm.

2. *Structural ordering of programs and data.* Structuring of software and its hierarchy in the block diagram, standardization of software structure units (modules) and variables help to reduce the number of errors during software development. The size of each software module at the autonomous modular development must meet the requirements of correct designing of complex functional software systems, particularly from the standpoint of programming methodology.

3. *Level of and design and testing automation.* Faultless systems of functional software system automatic design include a set of programming languages, compilers, tools for monitoring and verification of programs, advanced tools for conduction of planning and debugging, particularly languages of debugging, means of software documentation, specifications and programming software tools: operating environ, programming languages, software means for processes dynamics modeling in the controls object, signal generators and other simulators of outer surroundings, high performance computing networks. Computer-aided systems for software programming are not only the means of speeding up the design process, but also the means of ensuring a high level of accuracy of applications since they use a programming language of higher level compared with direct programming which use problem-oriented languages. Automated software programming system also makes it possible to conduct operations with more efficient debugging and to modify programs where detected errors.

4. *Choosing methods and criteria for debugging.* Multi-staging and structurization of debugging process enhances its effectiveness and reduces the amount of residual errors in the software design. An important factor is also the presence of debugging programs at each stage, choice and a clear formulation the debugging completion stages criteria as well as documentation for the processes and the debugging results, while also keeping up to the technologies of programs modification to eliminate design errors.

5. *Creation of instrumental milieu as close as possible to realistic.* Creating such a milieu, which is essentially a test software control module, plays a significant role at all stages of debugging since it allows tracing at the run of active computer numerical experiments, some types of errors that can be detected only during real operation while the consequences of such errors are certainly serious.

6. *Organizational and human factors.* This group of factors includes the number and expertise of specialists, the team structure and organizational interaction within it. The efficiency of such group is surely difficult to quantify, therefore it's is often used qualitymeric methods and expert opinions according a certain scale. It includes assessment of technical capabilities (knowledge, skills), level of initiative, degree of responsibility of programmers, parameters of results, degree of comfort at working conditions, taking into account the recommendations on the programmer psychology. In addition, the programmers interaction should be considered within the team performing common tasks, the degree of parallelism of development, role of project manager and executives at other levels in operational planning and performance evaluating, understandable organization, overall task of software development splitting into independent modules, an evaluation of technological stages of the development completion.

At the operational stage of software design reliability defining characteristics are completeness and accuracy of specifications; noise proof programs level, detection, diagnosis and documentation of abnormalities in the functioning of algorithms specific to the actual conditions, software function safe response for a deflection of algorithm (rejections, malfunction), full documentation of each change in programs caused by design errors that were detected. Direct consequence of the factors that complete the design stage and affect the reliability of software is the level of programming languages grade, programs adjusting and completeness of testing. Degree of these factors influence depends on the quality of design and debugging duration.

During support of programs are eliminated detected design errors and also the errors found during testing and debugging of software, programs are copied, adapted to the configuration of technical means in the new versions of system software, expanding the software complex functions. The major factor affecting the reliability or function of the software during this stage is its adaptation to the complex functional software upgrading in correlation with the expanded functions, compliance with the changes in configuration and other characteristics of hardware system; the complexity of the programs modification; effectiveness of upgrading control, programs modifications, status of the versions, their reproduction and operation.

It should be noted that during the software operation, as far as its errors are removed, relates them to the so-called "getting – young" systems, while the hardware at operation refers to as the "aging" systems.

3.6. Sources of formation and failure modes of systems

Changes that occur in time and space in any technological, including information systems lead to the loss of its efficiency due to external and internal sources of energy influence which act on the system during its operation. Concerning the effects of factors changing the reliability of the system, which were described in the previous sections of this chapter, there are three major sources of influence:

- energy of the environ action, including human, which serves as the operator and repairman,
- internal energy associated with workflows that occur in the system,
- accumulation of potential energy of materials from which is made the system.

A variety of forms of energy (mechanical, thermal, chemical, electromagnetic, nuclear etc.), which run in the system, induce within its constituent links and modules processes that change items state and properties of materials, that causes a change in their characteristics and parameters. These processes are associated usually with complex physical and chemical phenomena and lead to deformation, wear and other types of damage (deviation of control properties from their initial levels). The accumulation of such damage, in turn, leads to changes in initial system quality characteristics, which eventually lead to a failure.

Processes that reduce the efficiency of the system, by the value of its flow rate can be divided into three groups.

1. Fleeting processes have such changes periodicity that makes a small time fraction during the system operating cycle. These might include:
- vibration of parts and components,
- friction forces changes in moving joints,
- fluctuations in the level of operation, including electric, mode loads and other processes that change or make obstacles to the full-time duty cycle of a system.

2. Processes of medium speed, characterized with a periodicity which is compared with the duration of the system operating cycle. They lead to a monotonic change in the system characteristic output. These may include: reverse processes of thermal deformation caused by energy dissipation as workflows and daily fluctuations at ambient temperature.

The reverse processes (in contrary to irreversible) temporarily change the system characteristics output without progressive deterioration trend. It should be noted that in some cases reversible processes can initiate irreversible process that leads to damage accumulation.

3. Slow process is characterized by periodicity, which is compared with the duration of the overhaul period. They are:
- processes of parts wear,
- redistribution of internal stresses in details due to the materials aging process,
- creep of materials,
- corrosion processes,
- elements surface contamination.

Common methods to combat the effects of slow processes are periodic repairs and maintenance.

Damage and defects. Here we consider the damages and defects in the information systems classification. It is known that there is a following definition.

Damage – an incident that at the serviceable state of the system the disturbance still residues at its operation.

Types of objects damages, its components and corresponding failures can be divided into two groups.

1. *Allowable damages* occur during normal operation in a number of cases. Eliminate this type of damage is impossible, but it can be taken measures to slow down their emerging.

2. *Not allowable damage* outcomes from the presence of defects or random uncontrollable external factors that nondirectly related to the technical condition of the system under consideration (accidents, natural disasters etc.).

As a *defect is* understood every single discrepancy to the system established normative or design (project) documentation requirements, which reduce this system level of reliability.

It should be noted that the system which has a defect may be in working condition. The shortcoming is considered as a possible cause of failure, but the defect does not mean that a failure had occurred.

According the stage of origin, defects can be divided into three groups.

1. *Defects (errors) of projecting*. These might include:
- presence of stress concentrators in the details,
- incorrect calculation of basic details strength,

– wrong choice of materials,
– incorrect definition of operational loads etc.

2. *Defects of manufacturing (production).* These include defects of:
– components,
– machining,
– assembling of units, modules, subsystems during the creation of the system.

3. *Defects of operation.* These might include:
– breach in applications,
– incorrect maintenance and repair,
– existence of different, varying intensity and unexpected loads,
– use of substandard performance components.

We may consider one of the most important concepts in the fundamentals of information systems reliability – failures.

3.7. Classification of failures

In the reliability basics of information systems included classification of failures according the following number of features.

1) *Nature of failure occurrence*:
– *reason for refusal* – circumstances during design, manufacture or system use, which led to a failure;
– *failure mechanism, failure occurrence characteristics* – physical, chemical or other process that led to a rejection.

2) *Nature of failure considerations*:
– *accounted failure* – failure that has to be accounted in the explanatory note about testing, operation or calculative reliability values consequences; there also should be considered the criteria for failures accounting;
– *unaccounted failure* – refusal, which shall be excluded from the explanatory note of the testing consequences, operation and calculation of values of reliability; there should be set the criteria of such failure removal.

3) *Nature of system characteristics changes until the commencement of failure:*
– *sudden failure* – refusal that impossible to predict at the prior studies or at technical inspection;
– *phasing failure* – failure caused by gradual changes in the values of one or more system characteristics. Phasing failure can be foreseen at initial examining or at technical inspection, sometimes it can be prevented at maintenance proceedings.

4) *Opportunities of subsequent system use after failure occurrence:*
– *partial failure* – refusal that results in the inability of a system to conduct a part of the required functions;

- *complete failure* – refusal that leads to complete inability of the system to implement any of the required functions.

5) *Communication between system failures*:
- *dependant failure* – refusal of a system directly or indirectly caused by a failure or by malfunction of other system;
- *independent failure* – refusal of a system not caused directly or indirectly by a refusal or failure of another system.

6) A*vailability of failure external manifestations:*
- *an obvious failure – refusal which is manifested visually or by an authorized method of monitoring and diagnosing at preparation of a system to operation or in the course of its intended use*;
- *hidden failure* – refusal that cannot be detected visually or by regular methods of monitoring and diagnosis, but diagnosed at operation, at maintenance or by the special methods of diagnosis.

7) *Causes of failure:*
- *engineering failure* – refusal, caused by imperfections or connivance of the set rules and (or) design standards and construction of systems;
- *production failure* – refusal caused by a mismatch of productions to its design or to the norms of the production process;
- *degraded failure* – refusal, caused by degradation processes in the system, subjected but to all the rules and (or) the standards of design, construction and operation that were executed;
- *rejection because overload* – failure caused at using in the system some loads that exceed its established capacity;
- *rejection due to incorrect handling* – failure caused by improper or careless system use;
- *rejection as a result of fragility* – failure caused by frailty of the system, when the load on system does not exceed the system installed capacity.

8) *Ability to eliminate failure:*
- *systematic refusal* – refusal, clearly linked to a specific reason, which can be resolved only after modification the project or production process, rules of operation, documentation and other factors that are taken into account;
- *malfunction* – self-healing refusal or one-time refusal, which can be eliminated at operator intervention;
- *repetitive refusal* – self-healing refusal the same nature that occurs repeatedly.

9) *Severity of failure:*
- *resource refusal* – failure at which the system reaches the critical condition;
- *critical failure* – refusal that by estimations can result in personal injury or substantial property damage or other negative consequences.

Continuing further classification of failures, we can note the following.

In the technical systems reliability publications terminology are used terms "parameter", "characteristics" of system performance or reliability and also "reliability index". In this paper, these terms have the following interpretation:

- *parameter of performance or reliability* of the system, which changes over time, is a corresponding function of time, and is referred to as the *characteristic of performance or reliability,* and at a fixed time t value of the characteristic *parameter* it can be called relevantly parameter of *operation or reliability.* In other words, the term "parameter" in the theory of reliability of engineering systems is of limited meaning as an independent term, while more methodologically sound is the term "characteristic", which reflects the functional change of a parameter in general case and in time and space;
- *reliability index* is a well known common term (interpretation of which is quite practical, but at the same time it has no scientific justification for implementation in mathematical or technical terminology) and used as functional value, defined in the space of time reliability characteristics functions, and determined by the corresponding integral or differential operator.

It is known that the technical arrangements of hardware information systems are described by a large number of parameters and characteristics. Reliability functions of such facilities constitute a subset of them to possess specific properties. One of these features is characteristic of failures formation (accumulation) in the investigated technical facility. This may be an element, link, module, unit, and in some cases the entire technical system. In the following description such characteristic will be described generally by a random process $A(\omega, t)$. For each examined case such general model will be specified closely. Implementation of a random process $A(\omega, t)$ at fixed $\omega = \omega_1$ random event $\omega \in \Omega$ from the space of elementary events Ω will be defined as $A(\omega, t)/\omega = \omega_1 = A(t)$, and at fixed time moment $t = t_1$ we will have a random variable $\xi_1(\omega)$.

In order to illustrate better the overall process of system or some of its constituents (components, assemblies, parts, modules, devices etc.) failure forming, according to one of the areas of reliability study in Figure 3.2 we present the following algorithm scheme that reflects the operation control sequence over the system operation characteristic $A(t)$ changing as the failures formation characteristic.

The following graphs of realizations $A(t)$ of process $A(\omega, t)$ are illustrative, but they reflect the dynamics, the nature of changes and are confirmed by actual results of technical means research during operation.

Progressive (worn out) failures result from the gradual process of damage that leads to progressive deterioration of the system characteristics output. An example of such change implementation for the process $A(t)$ is illustrated on graph in Figure 3.3, where $t_{\hat{a}}$ – time of failure, and $A_{\max}$ – the value of characteristic $A(t)$, at which had happened the refusal.

Thus, it is accepted, that the major feature of phasing failure formation is monotonic increase of process of failures characteristic dependence from the system time to failure:

$$\lambda(t_2) > \lambda(t_1) \text{ at } t_2 > t_1.$$

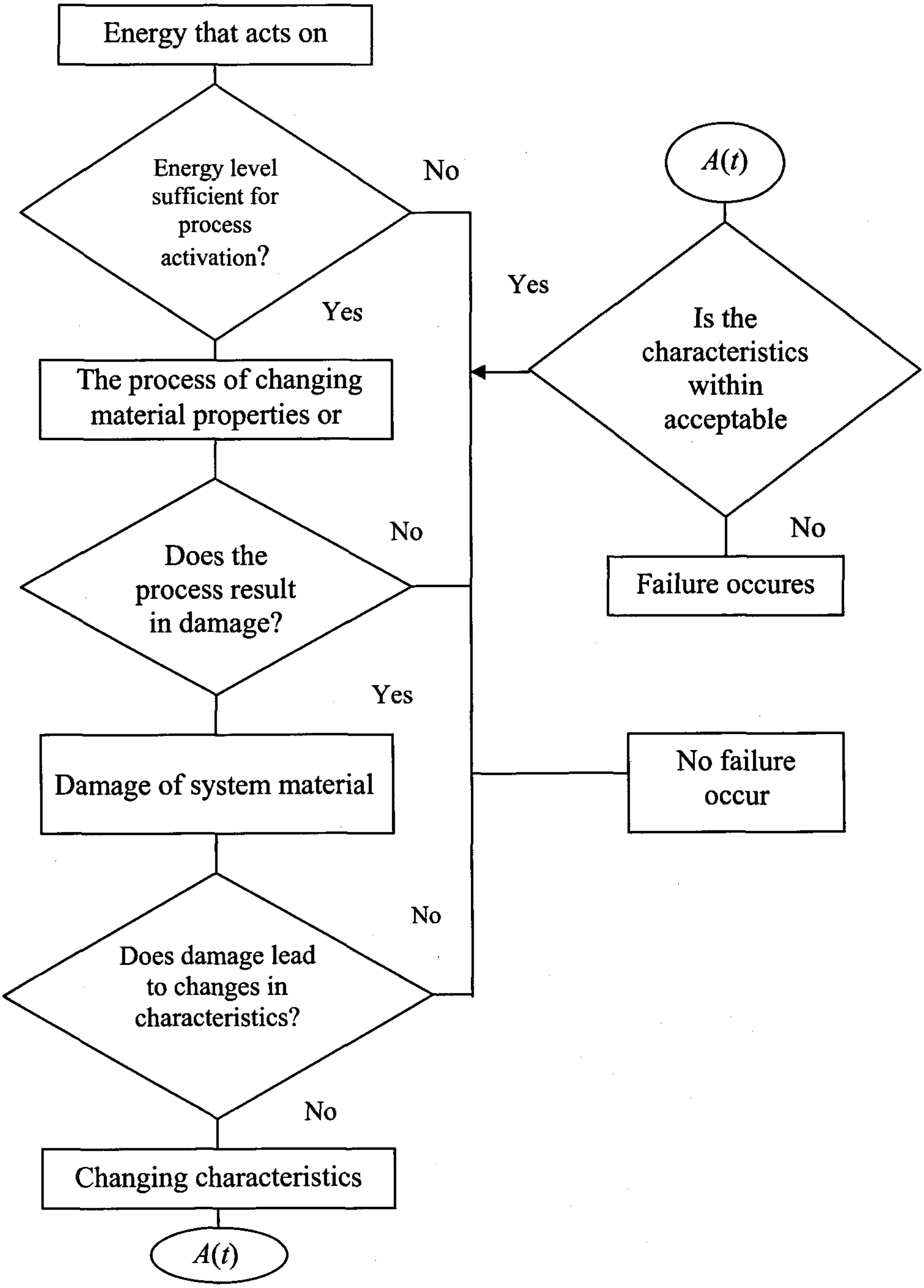

Fig. 3.2. Operation control algorithm simplified diagram on occurrence of failure in one of a system characteristics $A(t)$

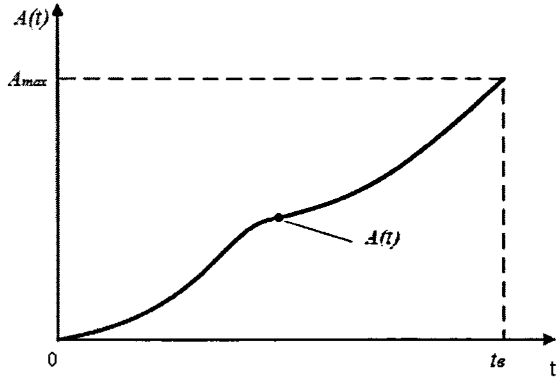

Fig. 3.3. Graph of gradual formation of failure process (wear out)

To this stipulation, corresponds for instance the normal distribution law – operating age to failure with *a* mathematical expectation and variance σ^2 which is widely used to simulate the phase-out of a system:

$$f(t)=\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(t-a)^2}{2\sigma^2}\right),\ R(t)=1-\Phi\left(\frac{t-a}{\sigma}\right),\ \lambda(t)=\frac{f(t)}{R(t)}.$$

To the phasing failures belong failures associated with the processes of wear, corrosion, fatigue and creep of materials.

With regard to information systems, the calculation of the phase-out reliability is conducted usually only for the technical resources and it is aiming to solve two problems, namely: optimal mode of electrical equipment choice, determination the technical resources reliability characteristics.

Calculation of information system hardware facilities reliability characteristics for phasing failure is conducted assuming that the gradual failure of individual elements of technical facilities are independent random events.

Sudden failures are results of unfavorable factors and random external influences combining exceeding the allowability of its perception. Sudden failures are characterized by spasmodic mode of the system damage degree dependence from time to failure (Fig. 3.4).

The major feature of sudden failure is independence of failure rate on operating time of the system, i.e., the probability of failure at a small range of time to failure depends only on the length of the interval, but does not depend on the previous time to failure of the system (is not related to the gradual accumulation of damages). Failures intensity serves as a mixed measure of both the random external factors intensity acting on the system during its operation and of the system's ability to withstand such actions. For simulation the sudden failures is applicable an exponential distribution law.

Failure which is the composite, that is the sum of the gradual and sudden failures, is called a *complex failure.*

As an example of a complex failure formation in Figure 3.5 is given the illustrative graph.

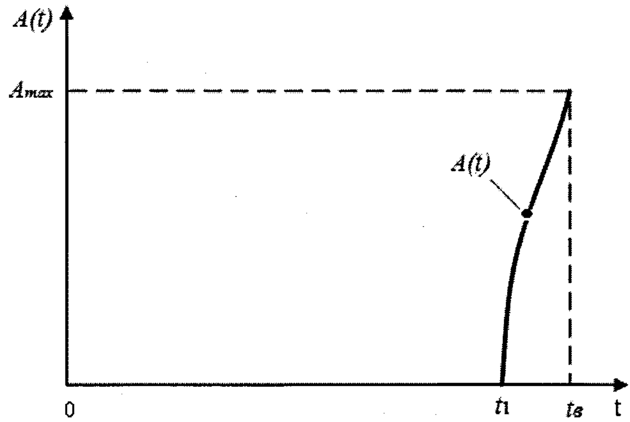

Fig. 3.4. Graph of the sudden failure process formation

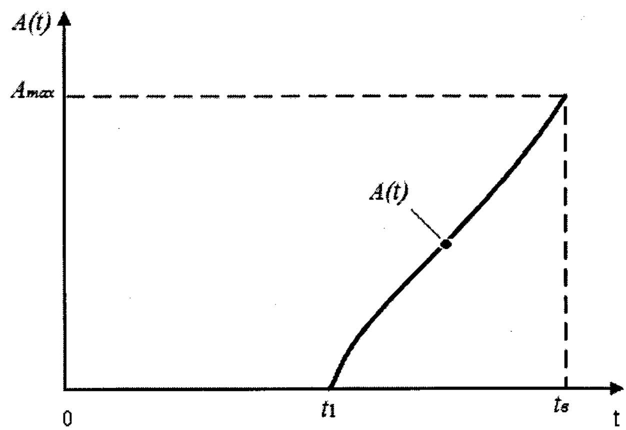

Fig. 3.5. The diagram of a complex failure formation process

Complex failure formation rate is greater than the rate of phasing failure and therefore less than the rate of a sudden failure. The latter can be significant, and in some cases it increases to infinity.

3.8. Examples of failure flows models

In the first chapter section 1.4.2 it was noted that the model of renewable systems reliability includes three constituents: the model of reliability, model of recovery and the operation control model.

In the models of renewable systems reliability are used appropriate models of flow failures. We consider these in detail.

Model of flow failures. In reliability theory is accepted the convention of the following types of failure flows as of random processes.

1. *The simplest failures flow* is stationary ordinary flow without aftereffects, which is described by Markov random process $\pi_1(\omega, t)$.

The number of failures n of this process $\pi_1(\omega, t)$ in the time interval $(0, t)$ is Poisson distribution with parameter $\alpha = \lambda t$ type

$$F_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}. \tag{3.1}$$

Mean (expected value) and variance of flow failures $\pi_1(\omega, t)$ at the time to failure t equal to each other:

$$\mathrm{M}\pi_1(\omega, t) = \mathrm{D}\pi_1(\omega, t) = \lambda t. \tag{3.2}$$

At $t = 1$ for a steady failures flow $\pi_1(\omega, t)$ have

$$\lambda(t)|_{t=1} = \lambda.$$

The distribution function of time to failure till the n-st failure is described by the Erlang distribution with parameters n and λ.

It is known that the Erlang distribution describes the distribution of n independent random variables with exponential distributions, each of which has a parameter λ, and the time to failure between failures per one failure has distribution:

$$F_n(t) = \mathrm{P}\{\omega \in \Omega : \pi_1(\omega, t) < \} = 1 - e^{-\lambda}. \tag{3.3}$$

So it comes, that to determine all characteristics of (3.1)–(3.3) for the simplest flow failures, we need to know the numerical value of parameter λ.

Non-stationary Poisson stream of failures is ordinary failures flow without after-action which is described by Markov random process $\pi_2(\omega, t)$. Basing on the two properties of the process $\pi_2(\omega, t)$ and namely:

- ordinariness of it means, that the probability of two or more events appearing on a small time interval $(t, t + \Delta t)$ is the value of a higher order of smallness (denoted $o(\Delta t)$ small), then the value of this interval Δt:

$$\lim_{\Delta t \to 0} \frac{\pi_2(t, \Delta t)}{\Delta t} = \lim_{\Delta t \to 0} o(\Delta t) = 0, \tag{3.4}$$

- aftereffect absence means that the probability of a certain number of failures appearing at a given time interval $(\tau, \tau + t)$ does not depend on how many refusals and in what time periods were appeared before a specified moment of time, while the conditional distribution function of a number of failures occurrence in the interval $(\tau, \tau + t)$ is unconditional distribution function, i.e.

$$F_n(\tau, \tau + t) = F_n(\tau, t)$$

for the specified average number of flow failures function or for a corresponding failures flow leading function $\Lambda(\tau, t)$ we have:

$$F_n(\tau,t) = \frac{\Lambda^n(\tau,t)}{n!} e^{-\Lambda(\tau,t)} \tag{3.5}$$

where:

$$\Lambda(\tau,t) = \mathrm{D}\pi_2(\omega,t) = \Lambda(\tau+t) - \Lambda(\tau).$$

At $\tau = 0$ the leading function of flow failures is $\Lambda(o, t) \equiv \Lambda(t)$, and in case when $\Lambda(t) = \lambda t$, the processes $\pi_2(\omega, t)$ are the simplest failures flow $\pi_1(\omega, t)$.

Generalized Poisson stream of failures is described by a random process $\pi_3(t)$ which, in contrary to a simple failure flow parameter, is described by parameter λ as of random variable $\lambda(\omega)$ with distribution function $F_\lambda(x)$. For the random variable $\lambda(\omega)$ the first two points are equal to:

$$a_1 = \mathbf{M}\lambda(\omega) = \int_0^\infty x dF_\lambda(x)$$

$$a_2 = \mathbf{M}\lambda^2(\omega) = \int_0^\infty x^2 dF_\lambda(x)$$

Probability of n failures in the process $\pi_3(t)$ during time to failure t is determined by the formula:

$$F_n(t) = \int_0^\infty \frac{(xt)^n}{n!} e^{-xt} dF_\lambda(\dot{x})$$

when $n = 0$ we have:

$$F_0(t) = \int_0^\infty e^{-xt} dF_\lambda(x)$$

Differentiating the last expression we obtain the following relation:

$$F_n(t) = \frac{(-t)^n}{n!} \frac{d^n}{dt^n} F_0(t), n = 1, 2, 3. \tag{3.6}$$

For $n = 1$ and $n = 2$ of (3.6) we obtain:

$$\Lambda(t) = \int_0^\infty xt dF_\lambda(x) = a_1 t$$

$$\mathbf{M}\pi_3(\omega,t) = \int_0^\infty (xt + x^2t^2) dF_\lambda(x) = a_1 t + a_2 t^2 \tag{3.7}$$

Basing on (3.7) we find the failures flow rate $\lambda(t)$ and number of failures variance:

$$\lambda(t) = \frac{d}{dt} \mathrm{M}\pi_3(\omega,t) = a_1,$$

$$\mathbf{D}\pi_3(\omega,t) = a_1 t + (a_2 - a_1^2) t^2.$$

Thus for the process $\pi_3(t)$ it takes place:

- flow rate of failures is independent of time and equals to the first initial moment a_1 which proves the stationary process $\pi_3(\omega, t)$,
- process $\pi_3(\omega, t)$ is also ordinary.

The presented examples of flow failure models which are used in the research of reliability models of renewable systems are typical, but they do not exhaust the set of random processes used in the technical systems reliability problems solution.

3.9. Illustrative graphic schemes of system failure formation

In general case, analysis of stochastic process of failures formation $A(\omega, t)$ is very complex, especially at the use of various mathematical models and their transformations in order to determine reliability characteristics. To specify these research results below will be shown graphic pictures of illustrative diagrams that describe the relevant examples.

As an example, it is presented a general scheme of system failure formation, using implementations and characteristics of the random process $A(\omega, t)$ which are illustrated with the corresponding curves in Figure 3.6. We discuss the description of graphs in this figure.

1. At $t = 0$ takes place a scattering of the initial values of the random process $A(\omega, t)_{t=0} = A(\omega, 0) = \xi_0(\omega)$ which is described by a random variable $\xi_0(\omega)$ with the truncated normal density probability distribution $f_0(x)$ and by the corresponding mathematical expectation $\mathbf{M}\xi_0(\omega) = a_0$. At the time interval $t \in [0, t_1]$ expectation process $A(\omega, t)$ is constant and unchanging, therefore $\mathbf{M}A(\omega, t) = \text{const} = a_0$.

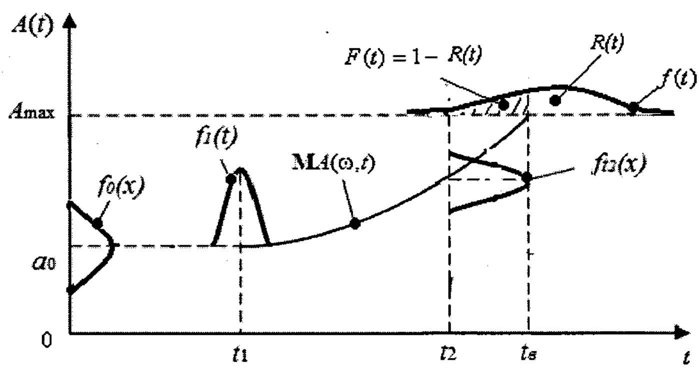

Fig. 3.6. Illustrated graphic scheme of the random process of failures formation $A(\omega, t)$ implementations and reliability characteristics

The presence of the initial values $\xi_0(\omega)$ scattering is associated with the production of elements of software errors and with the influence of random factors that occur at the initial phase of operation or during the test.

2. At $t = t_1$ start actions of various processes of medium speed, which in general begin to manifest itself after a certain time delay $t = t_1$. The denotation of the moment of delay is described by the random variable $A(\omega, t_1) = \xi_1(\omega)$ with mathematical expectation $\mathbf{M}\xi_2(\omega) = t_1$, with cutted off normal density distribution $f_2(t)$, and with $\mathbf{M}A(\omega, t_1) = a_0$. For the complex or sudden failures the delay time is determined by the starting of sudden random (unpredictable) factors that substantially accelerate system failure time emerging.

3. Moment in time $t = t_2$ is considered as the current time moment t in the system time to failure interval. Since the initial period of time to failure was considered earlier, i.e. at $t \in \{t_0, t_1\}$, moment of time t_2 was selected at the final period of system time to failure interval. The variation of the values in the random process $A(\omega, t)$ which describes the process of system failure forming can be defined by its derivative $g_A(\omega,t) = \frac{dA(\omega,t)}{dt}$. For a fixed time t_2 the speed value $g_A(\omega, t_2)$ is described by a random variable $\xi_{g_2}(\omega)$, probability distribution density of which is described by truncated normal law and is shown in Figure 3.6 as the graph of function $f_{g_2}(x)$.

In Figure 3.6 is given a graph of the density distribution $f(t)$ for distribution function of system failure $F(t)$ of the examined system, described by normal distribution.

4. Moment of time $t = t_в$ at which the mathematical expectation of a random process $\mathbf{M}A(\omega, t_1)/_{t = t_в} = A_{max}$ occurs a random event – failure of the studied system. In Figure 3.6 is given the graph of the reliability function $f(t)$ distribution density $f(t)$ which is described with the normal distribution law. As for the realization of a random process $A(\omega, t)$ in Figure 3.6 is presented the graph of mathematical expectation $\mathbf{M}A(\omega, t)$ as of an implementation of non-stationary random process. Using the model of non-stationary random process $A(\omega, t)$ enables, on the one hand, to consider a wide range of models of failures formation that occur in studies of system reliability characteristics, but on the other it substantially complicates the methodology of the study.

For example, for dynamics control of the process $A(\omega, t)$ in time, it is necessary to increase the number of tests, measurements, controlled values and characteristics of the process $A(\omega, t)$with subsequent experimental data for the following statistical processing. In other words, the results of solving the inverse problem of the theory of reliability in order to justify a system experimental reliability characteristics is relevant and important task in the modern theory of reliability and it requires considerable effort at using theoretical, simulation and experimental studies.

3.10. Examples of phasing failure typical models

To the known results of phasing failure study can be attributed a number of studies of the following phase-out models [2, 7].

1. We first consider the case where the values of the random process of failures formation $\mathbf{P}\{\omega \in \Omega : A(\omega, 0) = 0\} = 1$ at $\mathbf{P}\{\omega \in \Omega : A(\omega, 0) = 0\} = 1$ can be even to zero, i.e. at the beginning of the studied systems operation there is no rejection. Formally, this requirement can be written down as

$$\mathbf{P}\{\omega \in \Omega : A(\omega, 0) = 0\} = 1.$$

In practice, such requirement corresponds to a case when the scattering of values for process $A(\omega, t)$ realizations $A(0)$ is negligible and can be ignored in the studies. A common model for this case is as following,

$$A(\omega, t) = g_A(\omega) \cdot t,\ t > 0,\ A(\omega, t) \in [0, A_{\max}] \tag{3.8}$$

therefore the process of failures formation is a linear function of time – time to failure of the studied system.

Random variable $g_A(\omega)$ characterizes the rate of the process values change $A(\omega, t)$ and depends on a large number of random factors (operating load, regime and operating conditions), so the most typical case when $g_A(\omega)$ is described by the normal distribution law with density:

$$f_g(x) = \frac{1}{\sigma_q\sqrt{2\pi}}\exp\left[-\frac{(x-a_q)^2}{2\sigma_q^2}\right] \tag{3.9}$$

where a_q and σ_q^2 – corresponding mathematically expected values and random variable dispersion $g_A(\omega)$.

On the basis of (3.8) and (3.9) we obtain the following expression for the one-dimensional density distribution of a random process $A(\omega, t)$ in the form:

$$f(x,t) = \frac{1}{\sigma_q t\sqrt{2\pi}}\exp\left(-\frac{(x-a_1 t)}{2\sigma_q^2 t^2}\right).$$

Thus we have:

– function of the failures probability distribution

$$F(t) = \Phi\left(\frac{t-a_q t}{\sigma_q t}\right),$$

– distribution function of failure-free operation probability

$$R(t) = 1-\Phi\left(\frac{t-a_q t}{\sigma_q t}\right).$$

In Figure 3.7 are presented illustrative graphs of realizations $A(t)$ of random process of failure formation $A(\omega, t)$, which leads to a failure of studied system.

Graphs of process $A(\omega, t)$ implementations that are shown in Figure 3.7 describe the following types of failures:

- realization $A_1(t)$ illustrates very unlikely failure at time $t'_в$, with $R(t'_в) > F(t'_в)$ where $f(t)$ – failures probability distribution density (a),
- mathematical expectation $\mathbf{M}A(\omega, t)$, if this curve is seen as its appropriate implementation, then to it corresponds $F(t_0) = R(t_0) = 0{,}5$ (b),
- realization $A_2(t)$ has a higher probability of occurrence in practice, > 0.7, i.e. implementation of such model (3.8) more adequately reflects the character of failures, while $F(t''_в) > R(t''_в)$ (c).

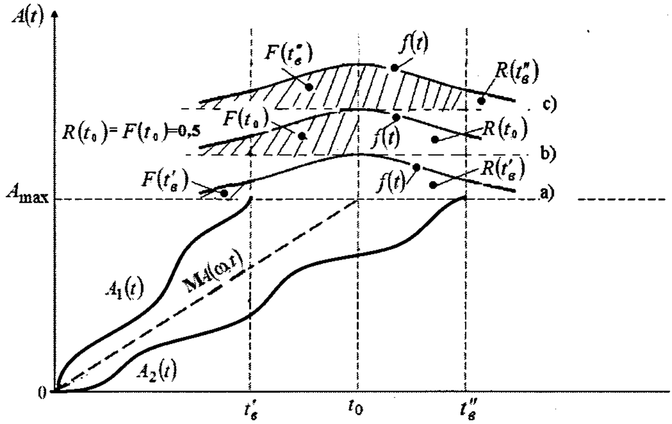

Fig. 3.7. Graphs of implementation $A_1(t)$, $A_2(t)$, $\mathbf{M}A(\omega, t)$ and relevant characteristics of system reliability at time of failures points: a) at time $t'_в$; b) at time t_0; c) at time $t''_в$

2. Below we consider a more complex compared to (3.8) following model

$$A(\omega,t)=\xi_0(\omega)+g_A(\omega)\cdot t,\ \ t>0,\ \ A(\omega,t)\in\left[0,A_{\max}\right] \tag{3.10}$$

which takes into account the initial scattering values of the process $A(\omega, t)$ at time $t = 0$, therefore $A(\omega,t)=\xi_0(\omega)+g_A(\omega)\cdot t,\ \ t>0,\ \ A(\omega,t)\in\left[0,A_{\max}\right]$.

In the model (3.10) for most practical cases are chosen following expressions for the random variables distribution density:

– for the random variable $\xi_0(\omega)$

$$f_0(x)=\frac{1}{\sigma_0\sqrt{2\pi}}\exp\left(-\frac{\left(x-a_0\right)}{2\sigma_0^2}\right),$$

– for the random variable $g_A(\omega)$

$$f_g(x)=\frac{1}{\sigma_g\sqrt{2\pi}}\exp\left(-\frac{\left(x-a_g\right)^2}{2\sigma_g^2}\right).$$

From the theory of probability it is known that the linear function (3.10) of two independent random variables distributed by the normal law also has a normal distribution with the parameters:

– mathematical expectation $\mathbf{M}A(\omega, t) = a_0 + a_g t;\ t > 0$,

– variance $\mathbf{D}A(\omega,t)=\sigma_0^2+\sigma_g^2 t^2; t>0$.

The process $A(\omega, t)$ probabilities distribution univariable density

$$f_A(x,t)=\frac{1}{\sqrt{\sigma_0^2+\sigma_2^2 t^2}\cdot\sqrt{2\pi}}\exp\left(-\frac{\left(x-\left(a_0+a_g t\right)\right)^2}{2\left(\sigma_0^2+\sigma_g^2 t\right)^2}\right).$$

Probability of a failure-free system operation at a definite time period (time to failure) t equals to the probability that the process of failures formation value $A(\omega, t)$ of a system at this point will fall in the range $[0, A_{max}]$ and it is given by the equation:

$$R(t) = 1 - F(t) = 1 - \Phi\left(\frac{t - (a_0 + a_g t)}{\sqrt{\sigma_0^2 + \sigma_g^2 t^2}}\right). \tag{3.11}$$

In Figure 3.8 is given illustrative graph for the accidental failures formation process $A(\omega, t)$.

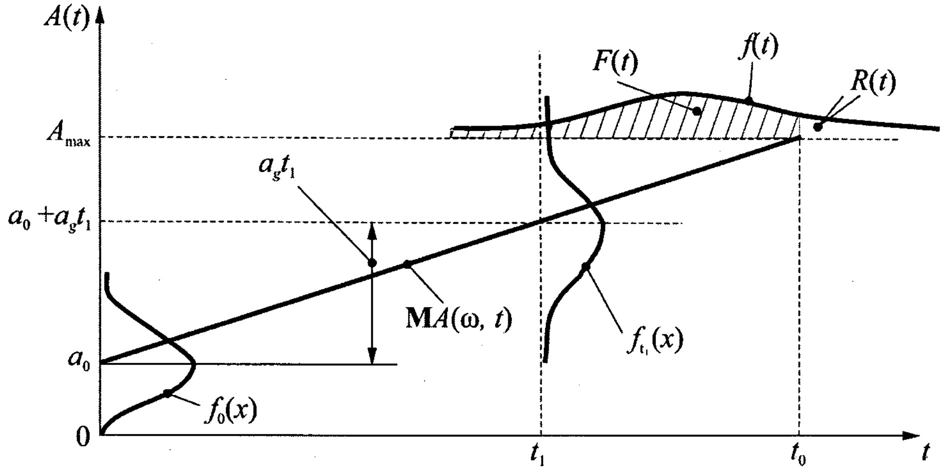

Fig. 3.8. Model of phasing failure based on initial parameters of a system scattering

The linear model of failures formation in the system $A(\omega, t)$ type (3.10) gives an opportunity to examine the contribution of different variants of two random variables $\xi_0(\omega)$ and $g_A(\omega)$ that describe different practical cases of failures formation, various operating conditions, effects of a variety of factors on the reliability characteristics.

Here presented a particular case of the following two:

2.1. Dispersion of process $\mathbf{D}A(\omega, t) < \varepsilon$, $\varepsilon > 0$ in the time interval of time to failure t of a system is small and can be ignored at the subsequent reliability characteristics calculations. In this case, the average time to failure of a system is

$$T_0 = \frac{A_{max} - a_0}{a_g}.$$

2.2. Values changing of the process $A(\omega, t)$ at a given time interval is small, and the initial dispersion, i.e. $\mathbf{D}\xi_0(\omega)$ is significant. In this case, to ensure the operability of a system at a given time interval it is required to take measures to increase the probability of system failure at the initial stage.

3.11. Modeling of sudden failures based on the exponential law

It is known that the origin of sudden failure is not related to those caused by gradual accumulation of damage system change over time but rather to the probability of sudden breakage within some interval (time) of time to failure and depends only on the length of this interval and on the failure rate. The ground for a sudden failure is a random adverse action of uncontrollable factors and external factors in excess to system perception opportunities. The characteristic of random external influences that can act on the system in operation and the possibility of its perception is the failure rate $\lambda(t)$ which, in case of sudden failures, is significant but constant $\lambda(t)$ = const value, and it is the major sign of a sudden failure.

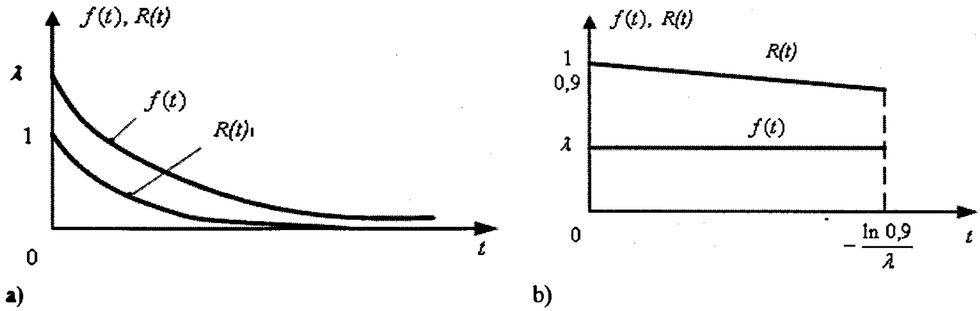

Fig. 3.9. Exponential law of a system major functions for reliability (a), and its approximation into the region of high reliability (b)

It is known that at using the exponential distribution law for the basic functions of reliability $R(t)$ and $F(t)$ we have:

$$R(t) = e^{-\lambda},\ F(t) = 1 - R(t) = 1 = e^{-\lambda},\ f(t) = \lambda e^{-\lambda} \tag{3.12}$$

and this is the very case of research that is widely used to simulate sudden failures.

The characteristics of reliability exponential law are:

1) mathematically expected value (first initial time moment, the average time to failure):

$$T_0 = \mathbf{M}\xi_1(\omega) = \int_0^\infty t f(t)dt = \lambda \int_0^\infty t e^{-\lambda t} dt = -te^{-\lambda t} \Big|_0^\infty + \int_0^\infty e^{-\lambda t} dt = \frac{1}{\lambda} e^{-\lambda t} \Big|_0^\infty = \frac{1}{\lambda},$$

2) variance (second central moment squared standard deviation):

$$\mathbf{D}(\xi) = \mathbf{M}(\xi_1^2(\omega)) - [\mathbf{M}\xi_1(\omega)]^2 = \int_0^\infty t^2 f(t)dt - \frac{1}{\lambda^2} = \lambda \int_0^\infty t^2 e^{-\lambda t} dt - \frac{1}{\lambda^2} =$$

$$= -t^2 e^{-\lambda t} \Big|_0^\infty + 2\int_0^\infty t e^{-\lambda t} dt - \frac{1}{\lambda^2} = 0 + \frac{2}{\lambda^2} - \frac{1}{\lambda^2} = \frac{1}{\lambda^2}$$

3) root-mean-square deviation:

$$\sigma=\sqrt{\mathbf{D}(\xi_1(\omega))}=\frac{1}{\lambda}=T_0. \qquad (3.13)$$

Taking into account (3.13), the formula for the failure-free operation probability can be represented as:

$$R(t)=e^{-\lambda t}=e^{-\frac{1}{T_0}}.$$

At transformation the last formula onto McLaren series:

$$R(t)=R(0)+\frac{dR(0)}{dt}t+\frac{d^2R(0)}{dt^2}\frac{t^2}{2!}+\frac{d^3R(0)}{dt^3}\frac{t^3}{3!}+...=1-\lambda t+\frac{(\lambda t)^2}{2!}-...$$

solution can be restricted to the two terms of the expansion and we obtain a linear approximation of the exponential law, which can be used for the calculations in the area of high reliability $R(t)\geq 0{,}9$ (Fig. 3.9b):

$$R_0(t)=1-\lambda t=1-\frac{t}{T_0}.$$

Expression of probability distribution density for approximated law is described by:

$$f_0(t)=-\frac{dR_0(t)}{dt}=\lambda=\frac{1}{T_0}.$$

From these equations it follows that in the area of high reliability (low values of time to failure), it can be figured out that the random variable $\xi(\omega)$ – time to failure to the failure of a system is uniformly distributed with the density λ = const.

The cause of sudden failure is not due to the change of the system, but determined with unfavorable combinations of operating factors, therefore it is required to build a model of sudden failure to evaluate the conditions which can lead to a failure and to estimate the probability of this event. Building a model of sudden failure is related to the analysis of operating conditions, operating mode, possibility of extreme loads and active influence of environment on the system performance.

In some cases, for the description of sudden failures is used a stationary stochastic process, whose characteristics $\mathbf{M}A(\omega, t)$ = const; $\mathbf{D}A(\omega, t)$ = const, and one-dimensional density probability distribution $f(x, t) = f(x)$ is independent on time, that is independent of the time to system failure. For example, the patterns of change of individual realizations $A_i(t)$; $A_k(t)$ for the i-st and k-st systems of the same species are characterized by various changes in the conditions and modes of operation, the random nature of operating loads and external influences on the i-st and k-st system in operation. Because of actions of various reasons there are observed different time moments t_1, t_2 – moments of failure corresponding to the i-st and k-st systems. Thus, in general case it is needed to use a special device for the emission of random processes realizations over the preset limits (borders), determining the likelihood of process $A(\omega, t)$ at implementation of crossing the confidence interval values limits borders for the process $A(\omega, t)$, therefore the departure of corresponding implementations $A_i(t)$; $A_k(t)$ out of interval of process confidence variables(process $A(\omega, t)$ tolerance values within a definite probability).

It should be mentioned here the restrictions in the use of stationary random process models for a sudden system failures.

For renewable systems in which proceeds a sudden failure under the action of random events, periods of serviceability alternate with time-lapse of recovery time.

For a simplest (Poisson) flow, the number of failures that occur within the time to failure interval length t is a random variable distributed according to the Poisson law. In this case, the probability of m failures in the interval length t is:

$$\mathbf{P}\{\xi(\omega) = m\} = \frac{(\lambda t)^m e^{-\lambda t}}{m!},$$

and the times to failure between each adjacent failure obey to the exponential distribution law:

$$R(t) = \mathbf{P}\{\xi(\omega) > t\} = e^{-\lambda t},$$

where the parameter λ has denotation of failure rate.

Mean time to failure in this case of simplest (Poisson) failure flow is $T_0 = 1/\lambda$.

Failures flows can be simple – when occur identical or similar system components rejections, and complex. In the latter case occurs a complex failures flow, which is the sum of n independent simple flows and corresponds to the chosen types of heterogeneous system components failures. The leading function of such complex failures flow, as of the mathematically expected values for the number of failures of the total operating time interval t, is the sum of the leading functions of simple flows components:

$$\Lambda(t) = \sum_{i=1}^{n} \Lambda_i(t).$$

Differentiating the last expression for t, we obtain an expression for the total intensity of type:

$$\lambda(t) = \sum_{i=1}^{n} \lambda_i(t),$$

therefore it characterizes the complex failures flows as the sum of the simple failures flows intensities.

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4. Backup of information systems

This section covers, in majority, methods and means of information systems hardware redundancy, which have found widespread use at the design and operation of engineering systems in the second half of the twentieth century. These methods and means of hardware redundancy of information systems do not exhaust the complete set of methods, but they reflect the general situation in modern information technology of systems redundancy. It should also be noted that these methods and techniques will be discussed in very compressed form and will reflect only the basic idea of backup [1–6].

4.1. Typical structures of systems

General questions of structuring. Information systems structures as the research objects can be divided into three groups by its properties; each of them conducts independent task.

Interaction with the surroundings (exchange contours, "input" and "output" of the system). Of primarily interest is the so-called target exchange contour that characterizes the required functions performing process (output effect gained in the system). For example, for the technological (information) systems, the objective is to share resources with consumer contour (material, energy, labor, information) that is resulted into a finished product. In addition to the target contour study it has to be considered the other exchange contours: power supply contour, efficiency providing contour, operation control contour and so on.

The internal construction ("structure"), refers to a set of elements and to a set of stable relations between them. The term "system structure" includes everything that determines the dynamics and logics of its operation, as a result it allows to describe formally, to simulate system functioning and predict the behavior on its basis. The detailing of the system structure consideration depends on the purpose of the study. In the simplest case it is possible to constrict the description only to the target contour. In more complex cases it must be accounted also for other exchange contours modeling, considering its hierarchy, presence in a definite system structure hosting solutions etc.

System-wide integrated qualities ("behavior") of system, which generally (for complex systems) may not be expressed in terms of properties which are included in the system elements. These systems properties comprise the following features.

1. System consumer values (A – quality, property of a system) are defined by the targeted contour and they are input, at introduction the concept "efficiency." Efficiency is usually understood as a favorable targeted exchange (proximity to the maximum of possible achievement).

2. Self organization (B – quality, property of a system) – the qualitative properties of systems of considerable complexity, to change its internal order, organization, structure, parameters, reorientation of behavior for improving the efficiency of the system as a function of operating conditions dynamics change. Self-organizing system is characterized by a set of features (and the respective levels of development), as far as critical becomes its ability for recognizing situations, adaptation, self-learning, freedom in availability of solutions, and so on.

3. Handling (C – quality, property of system), i.e. ability of a system to change its operation mode and to form control (controlled) actions to conduct the required functions.

4. Resistibility (R – quality, property of system) can combine various properties: strength, resistance to the action of external factors, reliability, survivability etc. Sometimes informational resistibility is distinguished as an isolated and independent group of properties.

Elements (links, modules, subsystems) of a system from the standpoint of information systems reliability analysis are characterized by the following features:

– an element is selected depending on the task, it can be quite complex in structure and design,
– element reliability characteristics refers to it as to one piece and not to its constituent parts,
– the possibility of elements restoring is independent from the other items of the system.

Output of such system elements regarding its influence on the output parameters of the system as of a whole can be divided into three groups (Fig. 4.1):

– X_1 parameter, change of which, as of a the target element parameter has only influence on the performance of the element itself,
– X_2 parameter involved in the formation of one or more output parameters of the system as a whole, its changes should be considered in conjunction with this category of the other system elements parameters changes,
– X_3 parameter that affects the performance of other system elements, its changes for individual items of a system are similar to the changes of the external operating conditions.

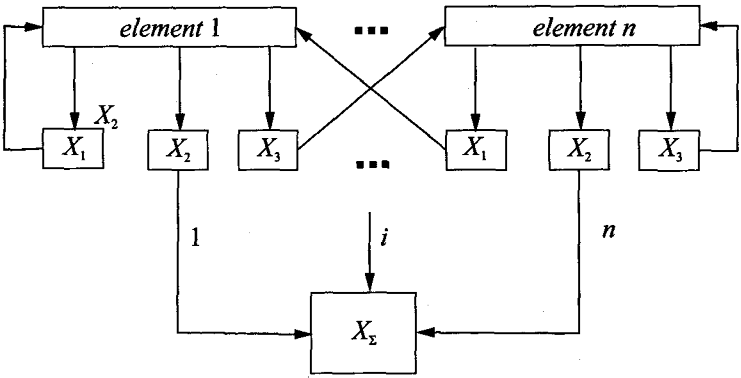

Fig. 4.1. Scheme of system elements output parameters interaction

It should be noted that each element of the output parameter can simultaneously have several mentioned above properties.

In terms of systems reliability they may have the following structures:

1) The detailed structure. Characteristics of system with detailed structure reliability are formed independently and can be pre-determined, as the result of failures in such system is treated as a random event, irrelevant to other system components status. All items of detailed systems have output parameters only such as X_1, which only affect the performance of the element itself;
2) The linked structure. This type of structures includes systems in which a failure of an individual element is a random event, the probability of which depends on the other elements state (elements have output parameters such as X_1). In such systems to consider the elements as isolated one from each other and to define its reliability characteristics is impossible. It is needed then to overview this system in a whole, and also to take into account a participation of each item that has output parameters such as X_2 in the formation of the output parameters of a system as a whole.
3) Combined structure. System with a combined structure is considered as its appropriate partitioning onto a subsystem with linked structure, thus determining of reliability characteristics for each of these subsystems is carried out independently.

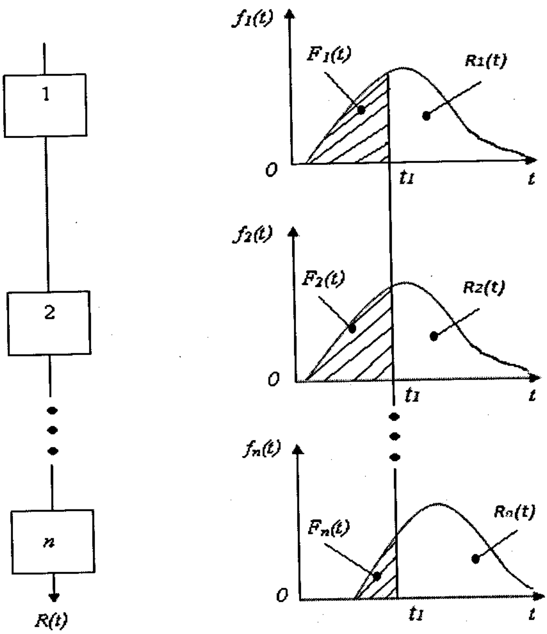

Fig. 4.2. Illustrative diagram of systems with serial connection of elements

We consider typical models of information systems structures.

Structure of system with serial connection of elements. Most typical systems reliability model is that with serial elements connection. These systems are systems in which a rejection of one only element can lead to disability of system as a whole. We consider a serially linked system that consists of n elements in more detail. This is due to the fact that it is used in most practical cases as a structure consisting of various parts, modules, devices, sub-systems connecting it into an integer system.

With each i-st element of the system for any given time (time to failure) are related two opposite random events:

- event A_i – operable state of i-st element, the probability of this event for an element of the system can be preset as $\mathbf{P}(A_1) = R_i(t) = p_i$,
- event $\overline{A_i}$ refusal of i-st element, the probability of this event is

$$\mathbf{P}(\overline{A}_1) = F_i(t) = q_i = 1 - p_i.$$

The structural formula for the event A (operable state of the system as a whole):

$$A = A_1 \times A_2 \times ... \times A_n = \prod_{i=1}^{n} A_i .$$

Based on a formula of multiplying the probabilities of the set of independent random events, the probability of failure of a system during the considered time (time to failure) t is described by:

$$\mathbf{P}(A) = R(t) = \prod_{i=1}^{n} \mathbf{P}(A_i) = \prod_{i=1}^{n} R_i(t) = \prod_{i=1}^{n} p_i \quad (4.1)$$

At exponential distribution of operating time to failure for each element (with only sudden failures), i.e. $R_i(t) = e^{-\lambda_i t}$, probability of failure-free operation is:

$$R_i(t) = e^{-\Lambda t},$$

where $\Lambda = \sum_{i=1}^{n} \lambda_i$ – system failure rate as the sum of the corresponding failure rates of its elements.

Mean time to failure is then $T_0 = \dfrac{1}{\Lambda}$.

Typical models of the information systems structures include the following.

The structure with parallel connection of elements. The systems with parallel structure include those in which a rejection of the entire system occurs when were refused all system's elements. More detailed description of such structure reliability will be discussed in 4.3.

The next model of system structure is most common within the classes of engineering, including informational, systems.

The structure of a system with composite connection of elements. Such system consists of sequential, parallel, mixed (sequence-parallel) and other connections type elements. To the latter types of connecting belong, for example, bridge structures, combining of elements type triangle or star. Calculations of reliability characteristics for such structures are difficult and

In most cases, there used appropriate methods of transformations and a study of equivalent units, accordingly to the schemes of sequential of parallel contours and onto other elements typical connections.

Rationalization regarding the structure of studied system is an important area of research in reliability theory. Especially it is important at the design stage of the system, at which are determined the estimated reliability characteristics of a system and its further evaluation at the stages of testing and operation.

4.2. Types of system backup

Reservation is one of the major ways to ensure a prearranged reliability level of a system at presence of insufficiently reliable components and elements. The purpose of redundancy – to ensure reliability of the whole system, i.e. to keep its performance if there occurred a failure of one or more elements.

Next are the following definitions.

Reservation – a method to ensure system reliability by the use of additional means and (or) features, redundant with respect to the obligatory minimal to perform the required functions.

At reserving by applying basic, reserved and system structure sparing elements, takes place a use of following types of redundancy.

Structural redundancy – redundancy using reserved elements of system structure. Structural redundancy is realized through inclusion into the reserve system such elements, which at the absolute reliability of the source object elements are not indispensable functionally. At structural elements (or chains) reserving, the reliability characteristics are enhanced discretely (by jumps).

Timing backup – backup using time slipping. Time slack can be used for maintenance, elimination of failures and so on. Reserving of time in information systems can be achieved in various ways:

- increase within operational time (by reducing the time for maintenance, for planned downtime, operation variability increase etc.),
- creating a margin performance,
- attributing to the system some properties of functional stability and durability.

Information backup – backup using the reserved information.

Implemented by introducing of redundant codes and symbols at the transmission, processing and display of information (such as additional units of information that can detect and correct errors during transmission, to correct the codes, to do parity check etc.).

Functional redundancy – redundancy, which uses system elements ability to conduct additional functions.

Using this method, system redundancy is built in such way, that a given function can be conducted in various ways and by different hardware.

Loaded backup – backup, which uses the ability of elements to take additional load as compared to nominal.

The essence of the principle of redundancy exercising is to expand the area of disability; with this, the region of system states moves off from the border line of performance, which is determined by the maximum allowable value of the output system characteristics. This is made by the creating a surplus of safety, wear resistance, vibration durability, thermal resistance and others.

Loaded redundancy allows continuously reliability improving of a system to the required level by increasing the capacity and stability against the individual system components failures. In the systems with linked or combined structures for setting up this level, it should be considered the operation of all systems on the basis of its elements and subsystems involving its individual components and subsystems in the formation the output system characteristics as of a whole, therefore for this case are distinguished:

- the major element – the element of the system, required to perform the preset functions without reserve,
- reserved element – the basic element, on the event of failure of which, in the system is provided one or more reserve elements,
- redundant element – an element intended to serve for a key element functions in the event of its failure.

In practice, there are various means of reservation:

- total redundancy – redundancy, which reserves the whole system,
- detached redundancy – reservation, in which are reserved some elements of an object or its group,
- redundancy with recovery – backup, at which the restoration of major and (or) reserved items in case of its failures is technically achievable without intervening the performance of the overall system and is allowed by operational documentation,
- backup without restoring – backup at which the major (or) redundant elements restoration, in case of its failures, is technically impossible without disturbing the performance of the whole system and (or) is not allowed by operational documentation,
- the opportunity of a successful transition to the reserve – an opportunity that the transition on reserve will proceed without reserve system failure, i.e. that it will take place during the time that does not exceed the permissible value for a break in operation and (or) without reducing the operation efficiency.

The major parameter for redundancy is its multiplicity, for which is given the following definition.

Multiplicity reserve – the reserve ratio of the redundant items multiplicity to the number of reserved elements, expressed by irreducible fractional number.

Duplication – redundancy with multiplicity reserve one for one.

There distinguished multiplicity reserve with integer and fractional multiplicity. To differ them in diagrams are indicating the multiplicity reserve m.

At reserving with a whole number multiplicity value, m is an integer, at fractional reserve the value of multiplicity m is an irreducible fraction.

For example, $m = \frac{4}{2}$ implies the presence of fractional reserve multiplicity, in which the number of reserve items is four, the number of basic – two, and the total number of elements equal to six. To reduce this fraction is impossible, since at reduction we get $m = \frac{4}{2} = 2$, and this, in turn, means, that there is a reserve with *a* integer number multiplicity, in which the number of reserve elements equals two, and the total number of elements is three, which is not correct.

By the way of incorporating, the redundancy is divided into a continuous, substitutional, sliding and mixed redundancy:

- continuous reservation, parallel redundancy – redundancy, that uses the loaded reserve in which, at refusal of any item in the backup group, the operation of object certain functions will be conducted without toggling the rest of elements,
- substitutional redundancy – redundancy, at which the functions of a key element are transmitted into backup only after he basic element failure,
- sliding redundancy – substitutional redundancy in which a group of basic elements is backed by one or more redundant elements, each of that can replace any of elements in this group in case of failure,
- mixed redundancy – a combination of various kinds of redundancy in a particular object.

At the reserve switching in, according the way of redundant item replacement until the time of its inclusion into operation, it can be present in a state of: loaded reserve; facilitated reserve; unloaded reserve.

4.3. Continuous backup of system elements

At continuous redundancy (Fig. 4.3) the backup items are permanently attached to the core item and from the very beginning of the system operation are in riskiness of failure. Formulas using events A_i – operational status and $\overline{A_i}$ – inoperable for the i – the element for the failure free operation and a failure for this system are shown therefore by [5]:

$$A = A_1 + A_2 + ... + A_n = \sum_{i=1}^{n} A_i,$$

$$\overline{A} = \overline{A_1} \times \overline{A_2} \times ... \times \overline{A_n} = \prod_{i=1}^{n} \overline{A_i}$$

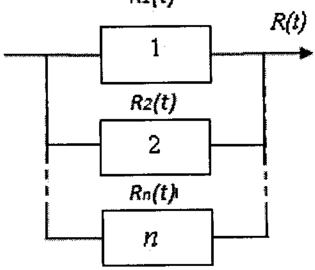

Fig. 4.3. The scheme with continuous system elements reservation

Basing on the structural formula of failure and using the multiplying formula for multitude of independent random events probabilities, the probability of system failure during the considered time t can be presented as:

$$F(t) = \mathbf{P}(\bar{A}) = \prod_{i=1}^{n} \mathbf{P}(\bar{A}_i) = \prod_{i=1}^{n} q_i = \prod_{i=1}^{n} (1 - p_i),$$

and, consequently, the probability of the system failure-free operation is

$$R(t) = 1 - F(t) = 1 - \prod_{i=1}^{n} (1 - p_i) \tag{4.2}$$

If all elements of a system are the same and the failures are occasional only, i.e. $p_i = e^{-\lambda t}$, then the probability of failure-free system operation is

$$R(t) = 1 - (1 - e^{-\lambda t})^n.$$

Distribution density function until the operating time to failure is

$$f(t) = -\frac{dR(t)}{dt} = \lambda n(1 - e^{-\lambda t})^{n-1}.$$

Intensively of system failures

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\lambda n(1 - e^{-\lambda t})^{n-1}}{1 - (1 - e^{-\lambda t})^n}.$$

From the last formula it follows that the failure rate at the beginning of the system is close to zero, i.e., the parallel systems reliability at short time to failure is high.

4.4. Substitutional backup

At substitutional reservation the redundant item is in disabled state and does not have a risk of failure from the moment of its switch in, which occurs in case of failure of the major (pre-contingence) element. In this case, it requires special controlling and switching devices that are used to detect failures and for the redundant element on duty switching in. We consider a system with replacement redundancy, consisting of primary and backup elements (Fig. 4.4).

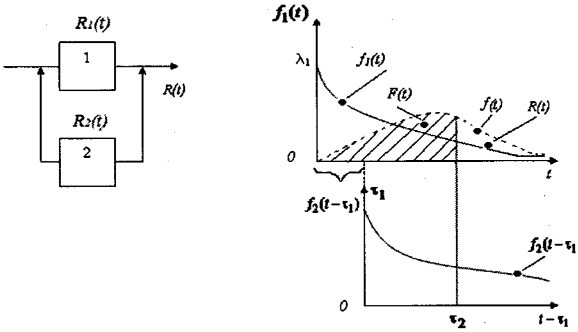

Fig. 4.4. Schemes and specifications for the items replacement reserving

Here refusals of items are considered as random and operating time to failure t of a system is distributed exponentially. Then the probability of elements failure-free operation is described by the expression:

$$R_i(t) = \mathbf{P}\{\xi_i(\omega) \geq t) = e^{-\lambda_i t},$$

where $i = 1, 2$ – numbering of items.

Distribution density function of operating time to failure for elements:

$$f_i(t) = \lambda_i e^{-\lambda_i t}, i = 1, 2 \tag{4.3}$$

Distribution density function operating time to failure for system of two elements $f(t)$ is the convolution of functions $f_1(t)$ and $f_2(t)$. Below we consider two cases.

1) Failure intensity of major and reserve elements is different, and then we have respectively:

$$f(t) = \int_0^t f_1(x) f_2(t-x)dx = \int_0^t \lambda_1 e^{-\lambda_1 x} \lambda_2 e^{-\lambda_2 (t-x)} dx =$$
$$= \lambda_1 \lambda_2 e^{-\lambda_2 t} \frac{1}{\lambda_1 - \lambda_2} e^{-(\lambda_1 - \lambda_2)x}\Big|_t^0 = \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2}\left(e^{-\lambda_2 t} - e^{-\lambda_1 t}\right).$$

Probability of failure – free operation:

$$R(t) = 1 - \int_0^t f(x)dx = 1 - \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2}\left(\frac{1}{\lambda_2} e^{-\lambda_2 t}\Big|_t^0 - \frac{1}{\lambda_1} e^{-\lambda_1 t}\Big|_t^0\right) =$$
$$= \frac{\lambda_2 e^{-\lambda_1 t} - \lambda_1 e^{-\lambda_2 t}}{\lambda_2 - \lambda_1} = -e^{-\lambda_1 t} + \frac{\lambda_1}{\lambda_2 - \lambda_1}\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right).$$

Mean time to failure for a system:

$$T_0 = \mathbf{M}\xi(\omega) = \mathbf{M}\xi_1(\omega) + \mathbf{M}\xi_2(\omega) = \tau_1, \tau_2 = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} = \frac{\lambda_1 + \lambda_2}{\lambda_1 \lambda_2} \tag{4.4}$$

where $\xi(\omega)$ – random variable of the first and second elements simultaneous rejection, $\xi_1(\omega)$ and $\xi_2(\omega)$ – accordingly, the values of failures of the first and second elements separately and τ_1, τ_2 – implementation of random variables $\xi_1(\omega)$ and $\xi_2(\omega)$.

2) The major and reserved items have the same failure rate, therefore we have:

$$f(t) = \int_0^t \lambda^2 e^{-\lambda x} e^{-\lambda(t-x)} dx = \lambda^2 t e^{-\lambda t}$$

Probability of failure – free operation of a system with two identical elements:

$$R(t) = 1 - \int_0^t f(t)dt = 1 - \lambda^2 \int_0^t t e^{-\lambda t} dt = e^{-\lambda t}(1 + \lambda t) \tag{4.5}$$

Summary of the last formula for a system with n identical elements can be obtained by application of $(n-1)$ – fold convolution of the distribution density function (4.3), in the form:

$$R(t)=e^{-\lambda t}\left[1+\lambda t+\frac{(\lambda t)^2}{2!}+\frac{(\lambda t)^3}{3!}+...+\frac{(\lambda t)^{n-1}}{(n-1)!}\right]=e^{-\lambda t}\sum_{j=0}^{n-1}\frac{(\lambda t)^j}{j!} \quad (4.6)$$

Mean time to failure of a system with n identical elements $T_0=\frac{n}{\lambda}$.

If it is required to take into account the influence of controlling devices failures, those that toggle switch, on the reliability of a system with replacement of items, then the right parts of formulas (4.4)–(4.6) must be multiplied by the reliability function of these devices.

In the Table 4.1 are given the calculation data for comparative assessment of continuous reserving and the redundancy by replacement method efficiencies (the elements are identical).

Table 4.1

Methods of continuous backup and redundancy replacement effectiveness comparative evaluation

Time to failure	**Probability of failure free operation**		
	one element	**continuous reservation**	**reservation replacement**
	$R(t)=e^{-\lambda t}$	$R(t)=1-(1-e^{-\lambda t})^2$	$R(t)=e^{-\lambda t}(1+\lambda t)$
$0.5\ t_1$*	0.60653	0.84518	0.90980
t_1	0.36788	0.60042	0.73576
$2\ t_1$	0.13534	0.25235	0.40601
$3\ t_1$	0.04979	0.09710	0.19915

*t_1 = 1/1 – mean time to failure of one element

Comparison of these data shows that substitutional redundancy is more effective method to improve the system elements reliability compared to constant (parallel contour) redundancy; with this a relative growth of failure-free operation probability becomes significant at the larger time to failure values.

4.5. Facilitated reserve

At the facilitated backup the reserve items until moment of switch are engaged in a facilitated mode and are characterized by failure rate intensively decrease. For the case when all elements (primary and backup) are identical and the failures are random (time to failure of elements is distributed exponentially) is formulated an approximate formula (by B. Hnedenko) which is valid at high probability of failure-free operation:

$$R(t)\approx 1-\frac{\lambda\cdot(\lambda+\lambda_1)\cdot(\lambda+2\lambda_1)\cdot...\cdot[\lambda+(n-1)\lambda_1]}{n!}\cdot t^n \quad (4.7)$$

where:

λ – failure rate at operating conditions,

λ_1 – failure rate in facilitated mode ($\lambda_1<\lambda$).

4.6. Reservation with restoration

For discovering the topic of backup with recovery, we consider the following examples. At study backup with recovery it is suggested that the function of reliability and recovery is described with exponential law. In this case the operation of the backup element is described by Markov random process. It is known that the process is called Markov's, if for every moment of time the opportunity of any future state of the system depends on the state of the system in this very moment and does not depend on the way how the system has come into this state via the past. Therefore, according this requirement all system past states are not taken into account.

Example 4.1. We consider first the simplest case of loaded backup for system from two items. Assume, that both failures and recoveries are independent events described by the exponential distribution law with following intensivities λ and μ respectively. Then the system can be present in one of three states:

- both items are serviceable,
- one item is in operation state, the other – under repair,
- both are in repairing.

Determine the probability p_{ij} of transition from and i-st state to j during some period of time Δt. Since the failure and recovery are independent events, then:

- $p_{11} = e^{-\lambda\Delta t} e^{-\lambda\Delta t} = 1 - 2\lambda\Delta t + \mathrm{o}(\Delta t\Delta t)$,
- $p_{12} = 2e^{-\lambda\Delta t}(1 - e^{-\lambda\Delta t}) = 2\lambda\Delta t + \mathrm{o}(\Delta t\Delta t)$,
- $p_{13} = (1 - e^{-\lambda\Delta t})(1 - e^{-\lambda\Delta t}) = \mathrm{o}(\Delta t\Delta t)$,
- $p_{21} = e^{-\lambda\Delta t}(1 - e^{-\mu\Delta t}) = \mu\Delta t + \mathrm{o}(\Delta t\Delta t)$,
- $p_{22} = e^{-\lambda\Delta t} e^{-\lambda\Delta t} = 1 - (\lambda + \mu)\Delta t + \mathrm{o}(\Delta t\Delta t)$,
- $p_{23} = (1 - e^{-\lambda\Delta t})e^{-\mu\Delta t} = \lambda\Delta t + \mathrm{o}(\Delta t\Delta t)$,
- $p_{31} = (1 - e^{-\mu\Delta t})(1 - e^{-\mu\Delta t}) = \mathrm{o}(\Delta t\Delta t)$,
- $p_{32} = 2(1 - e^{-\mu\Delta t})e^{-\mu\Delta t} = 2\mu\Delta t + \mathrm{o}(\Delta t\Delta t)$,
- $p_{33} = e^{-\mu\Delta t} e^{-\mu\Delta t} = 1 - 2\mu\Delta t + \mathrm{o}(\Delta t\Delta t)$,

where $\mathrm{o}(\Delta t\Delta t)$ – the remainder, which meaning tends to zero and its value relative to the previous components is of order smaller magnitude.

The resulting system of transition probabilities is conveniently represented as a matrix of transitions:

$$\{p_{ij}\} = \begin{Bmatrix} 1-2\lambda & 2\lambda & 0 \\ \mu & 1-(\mu+\lambda) & \lambda \\ 0 & 2\mu & 1-2\mu \end{Bmatrix} \qquad (4.8)$$

and the whole system in the form of directed graphs whose vertices are the probable states, and edges – possible transitions (Fig. 4.5).

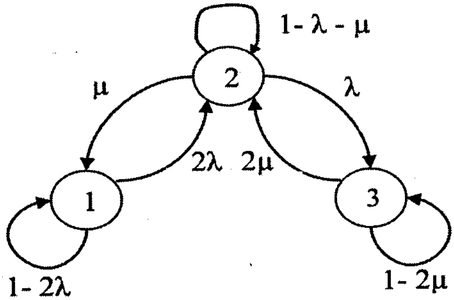

Fig. 4.5. System in the form of directed graph whose vertices are the possible states, and edges a possible transitions

Considering the transition probabilities and the formula of complete probability it is easy to formulate an equation by mutual linking the probability of p_i $(i = 1, 2, 3)$ of system residing in its respective states:

$$p_1(t+\Delta t) = \sum_{i=1}^{3} p_{i1} p_i(t) = (1 - 2\lambda\Delta t) p_i(t) + \mu\Delta t P_2(t),$$

$$p_2(t+\Delta t) = \sum_{i=1}^{3} p_{i2} p_i(t) = 2\lambda\Delta t p_1(t) + (1 - (\mu+\lambda)\Delta t) p_2(t) + 2\mu\Delta t p_3(t),$$

$$p_3(t+\Delta t) = \sum_{i=1}^{3} p_{i3} p_i(t) = \lambda\Delta t p_2(t) + (1 - 2\mu\Delta t) p_3(t).$$

Dividing the functions increments $p_i(t+\Delta t) - p_i(t)$ on Δt and passing to the limit (border) at $\Delta t \to 0$ we get.

$$\begin{aligned} \frac{dp_1(t)}{dt} &= -2\lambda p_1(t) + \mu p_2(t) \\ \frac{dp_2(t)}{dt} &= 2\lambda p_1(t) - (\mu+\lambda) p_2(t) + 2\mu p_3(t) \\ \frac{dp_3(t)}{dt} &= \lambda p_2(t) - 2\mu p_3(t) \end{aligned} \qquad (4.9)$$

at the initial conditions $p_1(0) = 1,\ p_2(0) = 0, p_3(0) = 0$. Knowing the probability $p_i(t)$ $(i = 1, 2, 3)$ it can be found the system readiness function $g(t) = p_1(t) + p_2(t)$. Thus, using (4.9) we have:

$$g(t) = \frac{\mu^2 + 2\mu\lambda}{(\lambda+\mu)^2} - \frac{\lambda^2 e^{-2(\lambda+\mu)t}}{(\lambda+\mu)^2} + \frac{2\lambda^2 e^{-2(\lambda+\mu)t}}{(\lambda+\mu)^2}.$$

Readiness index thus will be equal:

$$K_r = \frac{\mu^2 + 2\mu\lambda}{(\lambda+\mu)^2}.$$

In this case, for the determination of the coefficient of readiness K_r could just find at ing the value of the probability $p_{ij}(t)$, as

$$\frac{dp_i(t)}{dt} \approx 0.$$

Then from (4.9) and the set conditions that $p_1 + p_2 + p_3 = 1$ we obtain

$$p_1 = \frac{\mu^2}{(\lambda+\mu)^2}, \quad p_2 = \frac{2\lambda\mu}{(\lambda+\mu)^2}, \quad p_3 = \frac{\lambda^2}{(\lambda+\mu)^2} \qquad (4.10)$$

From there it is obtained an expression for the coefficient of readiness

$$K_r = p_1 + p_2 = \frac{\mu^2 + 2\mu\lambda}{(\lambda+\mu)^2}.$$

The ratio $\alpha = \dfrac{\dfrac{\mu^2+2\mu\lambda}{(\lambda+\mu)^2}}{\dfrac{\mu}{\lambda+\mu}} = 1 + \dfrac{\lambda}{\lambda+\mu}$ characterizes an increase in the coefficient of readiness K_r at items reserving. Since $1 < \alpha < 2$, then backup in any case leads to an increase of K_r.

For example, with a mean time to failure $t_{cp} = 19$ and mean time for repair $t_в = 1$, the index of readiness for a non reserved system $K_r = 19 / (19 + 1) = 0.95$, and thus at this value the ratio α is equal $\alpha = 1 + 1/20 = 1.05$.

Reservation system readiness index increases accordingly and equals

$$K_r = \frac{\mu^2 + 2\mu\lambda}{(\lambda+\mu)^2} = \frac{t_{cp}^2 + t_{cp}t_в}{(t_{cp} + t_в)} = \frac{399}{400} = 0.9975.$$

Note that in the presented calculating the time to failures intervals are not given in absolute units (hours, months, years), but in relative and dimensionless.

Similarly can be considered the facilitated and unloaded reserve cases. For example, instead of facilitated reserve transitions matrix (4.8) we may have

$$\{p_{ij}\} = \begin{Bmatrix} 1-(\lambda+\lambda_1) & \lambda+\lambda_1 & 0 \\ 0 \quad \mu & 1-(\mu+\lambda) & \lambda \\ 0 & 2\mu & 1-2\mu \end{Bmatrix},$$

where λ_1 – reserving item failure intensity rate.

At $\lambda_1 = 0$ we get a transition matrix for unloaded reserve. Apart from the considered above, possible are also other options. For example, at repair, when refused two elements, its restoration is carried out in sequence, then the matrix of transitions for an unloaded reserve has form:

$$\{p_{ij}\} = \begin{Bmatrix} 1-\lambda & \lambda & 0 \\ \mu & 1-(\mu+\lambda) & \lambda \\ 0 & \mu & 1-\mu \end{Bmatrix}.$$

For the reliability model enhancing the system must be to some extent changed. Since in practice of interest is the time during which the system from state 1 will switch into state 3, we will assume that in the state 3 system cannot switch into any other state, i.e. the transition matrix for unloaded reserve looks like

$$\{p_{ij}\} = \begin{Bmatrix} 1-\lambda & \lambda & 0 \\ \mu & 1-(\mu+\lambda) & \lambda \\ 0 & 0 & 1 \end{Bmatrix}$$

Hence we obtain

$$p_1(t) = -\lambda p_1(t) + \mu p_2(t),$$
$$p_2(t) = \lambda p_1(t) - (\mu+\lambda) p_2(t),$$
$$p_3(t) = \lambda p_2(t),$$

at

$$p_1(t) = -\lambda p_1(t) + \mu p_2(t),$$
$$p_2(t) = \lambda p_1(t) - (\mu+\lambda) p_2(t),$$
$$p_3(t) = \lambda p_2(t),$$

Solving this system in respect to $p_3(t)$ we obtain:

$$R_2(t) = 1 - \dot{p}_3(t) = \frac{\lambda_2 e^{-\lambda_1 t} - \lambda_1 e^{-\lambda_2 t}}{\lambda_2 - \lambda_1},$$

where:

$$\lambda_1 = \frac{2\lambda + \mu - \sqrt{\mu^2 + 4\lambda\mu}}{2}, \lambda_2 = \frac{2\lambda + \mu + \sqrt{\mu^2 + 4\lambda\mu}}{2}.$$

From there, the mean time of failure-safe operation for a system with unloaded reserve:

$$T_0 = \frac{1}{\lambda_2 - \lambda_1}\left(\frac{\lambda_2}{\lambda_1} - \frac{\lambda_1}{\lambda_2}\right) = \frac{\lambda_1 + \lambda_2}{\lambda_1 \lambda_2} = T_{cp}\left(2 + \frac{T_{cp}}{T_{в}}\right).$$

where:

$$T_{cp} = \frac{1}{\lambda}, \quad T_{в} = \frac{1}{\mu}.$$

Example 4.2. A complex consists of eight information systems and refuses in case of failure of six or more of these items (Fig. 4.6). Assuming that the failure and recovery of information systems are random and independent events with $\lambda = 10^{-4}$ and $\lambda = 10^{-2}$ hour^{-2}, we can determine:

- readiness function of complex $G(t)$, provided that $G(0) = 1$,
- coefficient of readiness of complex and compare it with the coefficient of readiness of failsafe system,
- function of complex reliability,
- the complex time to failure,

assuming that the failures emerge only within an operating complex.

The given complex may be presented in seven states (Fig. 4.6):

0 – all information systems are in service,

1 – seven information systems operate, one at recovery,

2 – six information systems operate, two at restoration etc.

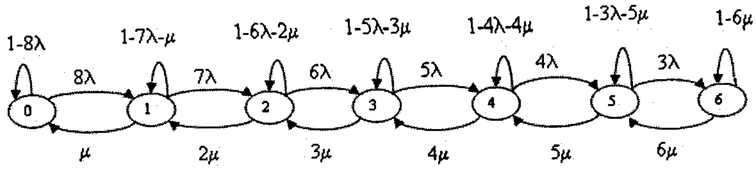

Fig. 4.6. Graph of disabled complex at refusal of six or more information systems

Probabilities p_{ij} of finding the complex in i-state are linked by correlation:

$$\begin{aligned}
p_0' &= -8\lambda p_0 + \mu p_1 \\
p_1' &= 8\lambda p_0 - (7\lambda + \mu) p_1 + 2\mu p_2 \\
p_2' &= 7\lambda p_1 - (6\lambda + 2\mu) p_2 + 3\mu p_3 \\
p_3' &= 6\lambda p_2 - (5\lambda + 3\mu) p_3 + 4\mu p_4 \\
p_4' &= 5\lambda p_3 - (4\lambda + 4\mu) p_4 + 5\mu p_5 \\
p_5' &= 4\lambda p_4 - (3\lambda + 5\mu) p_5 + 6\mu p_6 \\
p_6' &= 3\lambda p_5 + 6\mu p_6
\end{aligned} \tag{4.11}$$

$$p_0 + p_1 + p_2 + p_3 + p_4 + p_5 + p_6 = 1 \tag{4.12}$$

Function of complex readines equals $G(t) = 1 - p_6(t)$.

To determine the coefficient of readiness it is required to solve a system of algebraic equations, which can be obtained from the system (4.11) substituting p_i' for zero ($i = 0, 1,..., 6$). This change is due to the fact that at large values it approaches the border i, that means that p_i' tends to zero.

Adding the first equation to the second and third and so on, we get:

$$p_1 = \frac{8\lambda}{\mu} p_0; \quad p_2 = \frac{7\lambda}{2\mu} p_1; \quad p_3 = \frac{6\lambda}{3\mu} p_2;$$

$$p_4 = \frac{5\lambda}{4\mu} p_3; \quad p_5 = \frac{4\lambda}{5\mu} p_4; \quad p_6 = \frac{3\lambda}{6\mu} p_5.$$

Hence, from equation (4.12) we obtain:

$$p_0 + \frac{8\lambda}{\mu} p_0 + \frac{7\lambda}{2\mu}\frac{8\lambda}{\mu} p_0 + \frac{6\lambda}{3\mu}\frac{7\lambda}{2\mu}\frac{8\lambda}{\mu} p_0 + \frac{5\lambda}{4\mu}\frac{6\lambda}{3\mu}\frac{7\lambda}{2\mu}\frac{8\lambda}{\mu} p_0 +$$

$$+ \frac{4\lambda}{5\mu}\frac{5\lambda}{4\mu}\frac{6\lambda}{3\mu}\frac{7\lambda}{2\mu}\frac{8\lambda}{\mu} p_0 + \frac{3\lambda}{6\mu}\frac{4\lambda}{5\mu}\frac{5\lambda}{4\mu}\frac{6\lambda}{3\mu}\frac{7\lambda}{2\mu}\frac{8\lambda}{\mu} p_0 = 1$$

or

$$p_0 = \left(1 + \frac{8}{1}\left(\frac{\lambda}{\mu}\right) + \frac{8}{1}\frac{7}{2}\left(\frac{\lambda}{\mu}\right)^2 + \frac{8}{1}\frac{7}{2}\frac{6}{3}\left(\frac{\lambda}{\mu}\right)^3 + \frac{8}{1}\frac{7}{2}\frac{6}{3}\frac{5}{4}\left(\frac{\lambda}{\mu}\right)^4 + \right.$$

$$\left. + \frac{8}{1}\frac{7}{2}\frac{6}{3}\frac{5}{4}\frac{4}{5}\left(\frac{\lambda}{\mu}\right)^5 + \frac{8}{1}\frac{7}{2}\frac{6}{3}\frac{5}{4}\frac{4}{5}\frac{3}{6}\left(\frac{\lambda}{\mu}\right)^6\right)^{-1}.$$

For p_{ij} when $i > 0$, we obtain:

$$p_1 = \frac{8}{1}\left(\frac{\lambda}{\mu}\right)p_0; \qquad p_2 = \frac{8}{1}\frac{7}{2}\left(\frac{\lambda}{\mu}\right)^2 p_0; \qquad p_3 = \frac{8}{1}\frac{7}{2}\frac{6}{3}\left(\frac{\lambda}{\mu}\right)^3 p_0;$$

$$p_4 = \frac{8}{1}\frac{7}{2}\frac{6}{3}\frac{5}{4}\left(\frac{\lambda}{\mu}\right)^4 p_0; \quad p_5 = \frac{8}{1}\frac{7}{2}\frac{6}{3}\frac{5}{4}\frac{4}{5}\left(\frac{\lambda}{\mu}\right)^5 p_0; \quad p_6 = \frac{8}{1}\frac{7}{2}\frac{6}{3}\frac{5}{4}\frac{4}{5}\frac{3}{6}\left(\frac{\lambda}{\mu}\right)^6 p_0.$$

Accordingly, at $\lambda = 10^{-4}$ and $\mu = 10^{-2}$ time^{-1} we get

$$K_r(t) = 1 - p_0 = 1 - \frac{28 \cdot 10^{-12}}{1{,}0882856705628} \cong 1 - 26 \cdot 10^{-12}.$$

To determine the operating time to failure it is required to know the function of reliability. For this purpose the complex's graph needs to be changed so, that from the state of complex refusal the information systems could not escape from this state (Fig. 4.7).

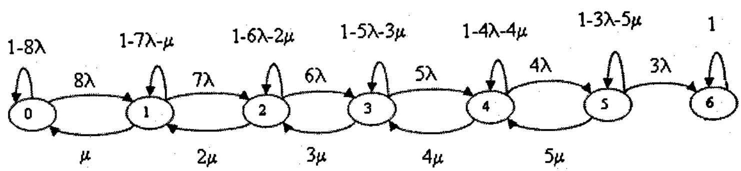

Fig. 4.7. Modified complex's graph

According to this graph we compile the equation similar to equation (4.11) and solve it. The results in accordance to the solution are

$$R(t) = 1 - p_6(t).$$

Below we consider the following type of reservation.

4.7. Partial redundancy (system k with n)

Particular case of parallel system is a system with n parallel-connected elements, which fail at such number of elements that the refuse more or equal to k times. For such a system, in which all elements are the same, i.e. the probability of failure of elements is within a certain time to failure t where $\mathbf{P}(A_i) = p$ and probability of failure $\mathbf{P}(\overline{A_i}) = q = 1 \; p$ for all $i = 1, 2, ..., n$, then for calculation of events probability can be to applied Bernoulli scheme (binomial distribution). Subsequently the probability that during the time to failure t in the system will happen k failures (or $(n - k)$ employable elements) is equal:

$$F_k(t) = C_n^k p^{n-k} q^k$$

where $C_n^k = \dfrac{n!}{k!(n-k)!}$ – the number of connections from n elements on k.

Reliability of the failure free system operation:

$$R(t) = \sum_{k<r} R_{n-k}(t) = \sum_{k=0}^{r-1} R_{n-k}(t) = \sum_{k=0}^{r-1} C_n^k p^{n-k} q^k \qquad (4.13)$$

Below we consider the subsequent types of backup.

4.8. Majoritarian redundancy

One more option of structural redundancy is majoritarian backup (using "voting"). This method is used in the data transmission lines; it is based on the use of an additional item – the majoritarian or quorum-element. This element conducts comparing the signals from the parallel-connected elements which perform the same function and passes on the system output the signal, which comes from majority of elements (Fig. 4.8).

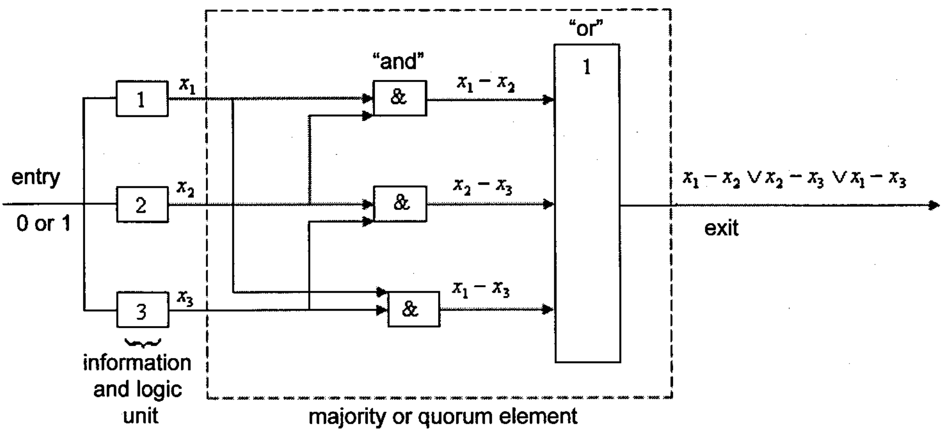

Fig. 4.8. Majoritarian redundancy scheme "two from three"

The main advantage of this redundancy method is ensuring the reliability at diverse types of failures. For example, in the absence of a quorum-element and failure type the "breakage" (at the output of rejected information and logical drive the signal is always 0) permanent reserve increases system reliability and at failures type "short circuit" (at the output of denied information-logical drive signal continuously equals 1) reliability of parallel connected elements system is lower than for a particular device without reserve and the risk of failure increases. Switch in the quorum-element eliminates this risk by providing correct signal transmission from input to output in case of any type particular device failure from the three.

4.9. Converting the block diagramby an equivalent replacement of triangle into star

Below we consider the method of system reliability structure model converting by means of equivalent replacement type "triangle – star" (Fig. 4.9).

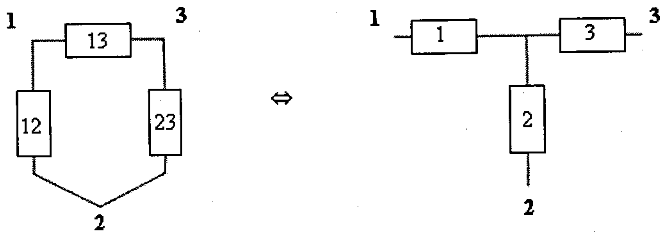

Fig. 4.9. The block diagram of the equivalent replacement triangle into star

Structural formula of random events $\overline{A}^{*}_{12}$ – failure in the system between nodes 1 and 2 – looks like a scheme for the "triangle" and the scheme for "star":

$$\overline{A}^{*}_{12} = \overline{A}_{12} \cdot (\overline{A}_{13} + \overline{A}_{23}) = \overline{A}_{1} + \overline{A}_{2} \qquad (4.14)$$

Similarly:

$$\overline{A}^{*}_{23} = \overline{A}_{23} \cdot (\overline{A}_{13} + \overline{A}_{12}) = \overline{A}_{2} + \overline{A}_{3} \qquad (4.15)$$

$$\overline{A}^{*}_{13} = \overline{A}_{13} \cdot (\overline{A}_{12} + \overline{A}_{23}) = \overline{A}_{1} + \overline{A}_{3} \qquad (4.16)$$

where $\overline{A}_{ij}$, $(\overline{A}_{i})$ – random events – failures of corresponding contour elements of scheme "triangle" ("star") $i, j = 1, 2, 3$.

Using the formula of summation of probabilities common of random events $\mathbf{P}(A + B) = \mathbf{P}(A) + \mathbf{P}(B) - \mathbf{P}(A \cap B)$, on the basis of formulas (4.14)–(4.16), it is possible to compile the system of three equations (the probability of failures q_i or (q_{ij}) of individual elements are assumed as known, since the system has by-item highlighted structure):

$$q_{12}(q_{13} + q_{23} - q_{13}q_{23}) = q_1 + q_2 - q_1q_2 \tag{4.17}$$

$$q_{23}(q_{12} + q_{13} - q_{12}q_{13}) = q_2 + q_3 - q_2q_3 \tag{4.18}$$

$$q_{13}(q_{12} + q_{23} - q_{12}q_{23}) = q_1 + q_3 - q_1q_3 \tag{4.19}$$

Ignoring at the left side of equations (4.17)–(4.19) results of triple multiplication of failure probabilities $q_i q_j q_k$, and at the right side – the products of double multiplication of possible failures $q_i q_j$, we get:

$$q_{12}q_{13} + q_{12}q_{23} = q_1 + q_2 \tag{4.20}$$

$$q_{13}q_{23} + q_{12}q_{23} = q_2 + q_3 \tag{4.21}$$

$$q_{12}q_{13} + q_{13}q_{23} = q_1 + q_3 \tag{4.22}$$

Solving the system of equations (4.20)–(4.22) with respect to q_i, we obtain the formula for "triangle – star" converting:

$$q_1 = q_{12}q_{13} \tag{4.23}$$

$$q_2 = q_{12}q_{23} \tag{4.24}$$

$$q_3 = q_{13}q_{23} \tag{4.25}$$

Formula of reverse transformation "star – triangle":

$$q_{12} = \sqrt{\frac{q_1q_2}{q_3}} \tag{4.26}$$

$$q_{23} = \sqrt{\frac{q_2q_3}{q_1}} \tag{4.27}$$

$$q_{13} = \sqrt{\frac{q_1q_3}{q_2}} \tag{4.28}$$

4.10. General and separate reservation

Taking into account the system, which consists of n serial-connected elements, it is useful to consider several options of its redundancy.

General reserve (Fig. 4.10a) provides, that in case of any element failure in the major chain is switched in the backup contour that completely replaces the core one.

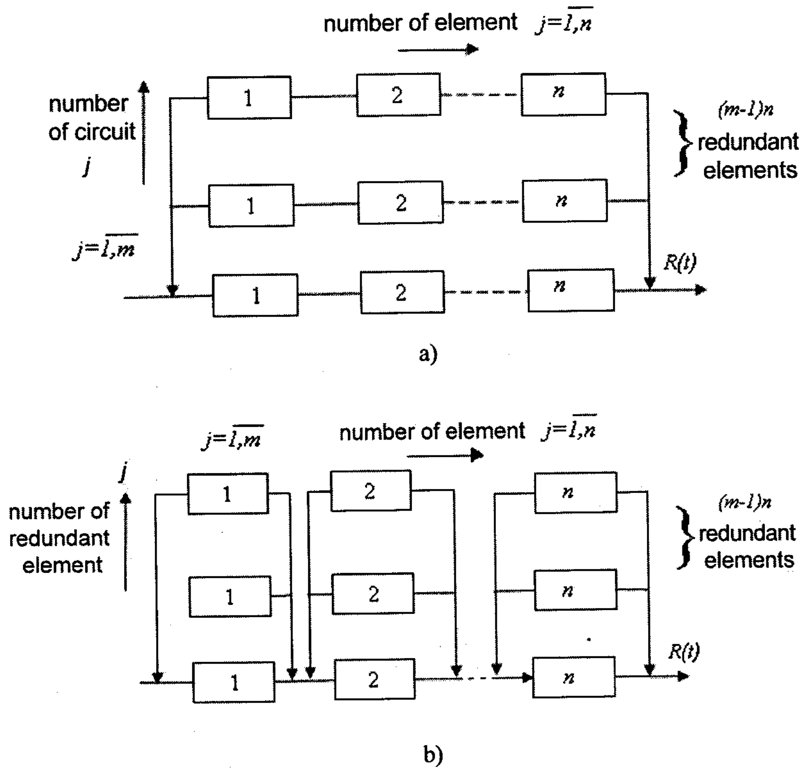

Fig. 4.10. General scheme of general (a) and separated (b) items reserving

Reliability of j – contour operation

$$R_j(t) = \prod_{i=1}^{n} R_{ij}(t)$$

where $R_{ij}(t)$ failure free operation probability of i-st element of j-st chain relative to the considered position in time t.

Probability of failure free operation of object from m parallel chains (in order to simplify the analysis reservation we reckon it loaded):

$$R(t) = 1 - \prod_{j=1}^{m}\left[1 - R_j(t)\right] = 1 - \prod_{j=1}^{m}\left[1 - \prod_{i=1}^{n} R_{ij}(t)\right] \qquad (4.29)$$

If all objects have the same reliability, i.e. $P_{ij}(t) = p$, then:

$$R(t) = 1 - \left(1 - p^n\right)^m \qquad (4.30)$$

For general and selective backup's essence disclosure, we shall consider the following examples.

nple 4.3. Probability of failure free operation of a facility with total redundancy $n = 3; p = 0.8$ will compose:

$$R(t) = 1 - (1 - 0.8^4)^3 = 0.7942.$$

servation absence the failure free operation probability for a series connected object from $n = 4$ elements at $p = 0.8$ will make:

$$R(t) = p^n = 0.8^4 = 0.4096.$$

rate reservation (Fig. 4.10b) ensures the inclusion of another backup facility in case ect of major chain fails.

parated reservation failure free operation probability for i-st element with the count- 1 redundant elements (reserve is considered loaded) will make:

$$R_i(t) = 1 - \prod_{j=1}^{m}[1 - R_{ij}(t)]$$

ability of failure free operation of facility with separate redundancy

$$R(t) = \prod_{i=1}^{n} R_i(t) = \prod_{i=1}^{n}\left\{1 - \prod_{j=1}^{m}\left[1 - R_{ij}(t)\right]\right\} \quad (4.31)$$

elements have the same failure free reliability, i.e. if $R_{ij}(t) = p$, then

$$R(t) = \left[1 - (1 - p)^m\right]^n \quad (4.32)$$

nple 4.4. Probability of failure free operation of facility with total redundancy $n = 3; p = 0.8$ will make:

$$R(t) = \left[1 - (1 - 0.8)^3\right]^4 = 0.9684.$$

ssment of calculations results described in examples 1 and 2 shows that the separate n provides a higher level of reliability in comparison with the general reservation ame number of redundancy (backup multiplicity).

ould be noted that the separated reserving leads to complication of the structure the need to use a larger number of controls and devices that are switched in, and e it diminishes its usage effect.

e have found also the *mixed redundancy* – combination of general and backup reservation with separate backup for the most critical and least reliable compo- mparing of backup options in this case can be made by the same method.

1. Training of elements and systems

ern information systems use a large number of items, the reliability of which, taken determines the system reliability. Some types of items at the initial stage of work ate some larger failures intensity rates (Fig. 4.11).

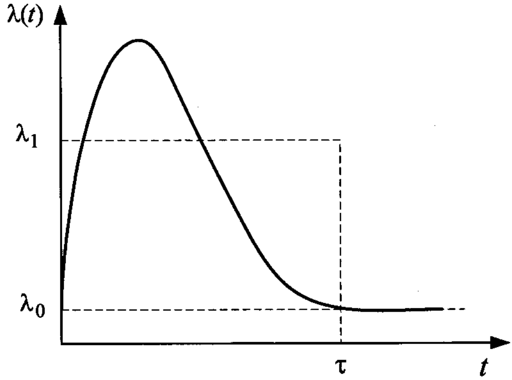

Fig. 4.11. Graph of failure rate change $\lambda(t)$ vs. time

In such case, in order to increase the reliability of such elements, they are subjected to training, and for some types of items the training is a must. Another, already known method of reliability increase is the backup. Below we give a typical example, which compares two methods of reliability improvement, namely such as loaded redundancy method with training of items aimed to improve reliability.

Example 4.5. Let denote: λ_0 – initial value, $\lambda_1 = \frac{1}{\tau}\int_0^\tau \lambda(t)\,dt$ – the average value λ during time to failure τ; $p \quad e^{-\lambda\tau}$ – faultless operation probability for the same period; T_{kn} – average reserve group of elements operation lifetime with multiplicity of redundancy k and provided that n elements from this group ($n \le k$) were subjected to training during time τ; C_{kn} – the cost of the backup group of elements.

To continue, we will consider only a case when in the backup group either all elements are untrained ($k = 0$) or all are trained ($n = k$), and the reserve is loaded. Items that are out of order are not restored and its preventive maintenance is not conducted. In addition, at training process the items parameters are not changed.

If to make stepwise approximation where λ – elements characteristic (Fig. 4.11) as:

$$\lambda(t) = \begin{cases} \lambda_1 & \text{at} \quad t \le \tau, \\ \lambda_0 & \text{at} \quad t > \tau, \end{cases}$$

then it is possible to calculate T_{k0} and T_{kk}.

For the trained items $\lambda(t) = \lambda_0$, $R_T(t) = e^{-\lambda_0 t}$,

$$T_{kk} = \frac{1}{\lambda_0}\sum_{i=1}^{k}\frac{1}{i}. \tag{4.33}$$

For the untrained items

$$R_H(t) = e^{-\int_0^t \lambda(t)dt} = \begin{cases} e^{-\lambda_1 t} & \text{at} \quad t < \tau, \\ e^{-\lambda_1\tau - \lambda_0(t-\tau)} & \text{at} \quad t \ge \tau. \end{cases}$$

Since $\lambda_1 > \lambda_0$ then $R_T > R_H$. If to select the following time intervals, and namely the interval from 0 to τ and correspondingly the interval from τ to ∞, then we obtain:

$$T_{k0} = \frac{1}{\lambda_0}\sum_{i=1}^{k}\frac{1}{i} - \left(\frac{1}{\lambda_0} - \frac{1}{\lambda_1}\right)\sum_{i=1}^{k}\frac{(1-p)^i}{i} \tag{4.34}$$

At comparison of expressions for R_T and R_H, T_{kk} and T_{k0} it follows that the training of elements increases both their reliability and also the time between failures.

We may assume that before the training there were m elements of total cost $C_{10}m$. Then after the training will be operable only pm items with a total cost of $C_{11}pm$. If not taking into account costs associated with the organization and conducting of training, then $C_{11}pm = C_{10}m$ or $C_{11} = \frac{C_{10}}{p}$. Hence we have:

$$C_{k0} = kC_{10},\ C_{kk} = kC_{11} = k\frac{C_{10}}{p} \tag{4.35}$$

To compare various methods for reliability improving it is convenient to use a concept of items specific lifetime $t_{kn} = \frac{T_{kn}}{C_{kn}}$. If to assume that $\lambda_0 = 1$ and $C_{10} = 1$, then from (4.33)–(4.35), we obtain:

$$\begin{gathered} T_{k0} = \sum_{i=1}^{k}\frac{1}{i} - (1-\alpha)\sum_{i=1}^{k}\frac{(1-p)^i}{i},\ T_{kk} = \sum_{i=1}^{k}\frac{1}{i},\ C_{k0} = k,\ C_{kk} = \frac{k}{p}, \\ t_{k0} = \frac{1}{k}\sum_{i=1}^{k}\frac{1}{i} - \frac{(1-\alpha)}{k}\sum_{i=1}^{k}\frac{(1-p)^i}{i},\ t_{kk} = \frac{p}{k}\sum_{i=1}^{k}\frac{1}{i} \end{gathered} \tag{4.36}$$

where $\alpha = \frac{\lambda_0}{\lambda_1}$. As $0 < \alpha < 1$ and $0 < p < 1$ then

$$T_{k+1,0} > T_{k0},\ T_{k+1,k+1} > T_{kk},\ T_{kk} > T_{k0},\ t_{k+1,0} < t_{k0},\ t_{k+1,k+1} < t_{kk},\ t_{kk} < t_{k0}.$$

Thus, both backup and training rise the average lifetime of the elements T_{kn}, but reduce the specific lifetime t_{kn}. If to compare T_{k0}, T_{rr}, t_{k0} and t_{rr} at $k \neq r$, then, depending on α or p, it should be preferred either reserving of trained items or untrained elements redundancy (Fig. 4.12).

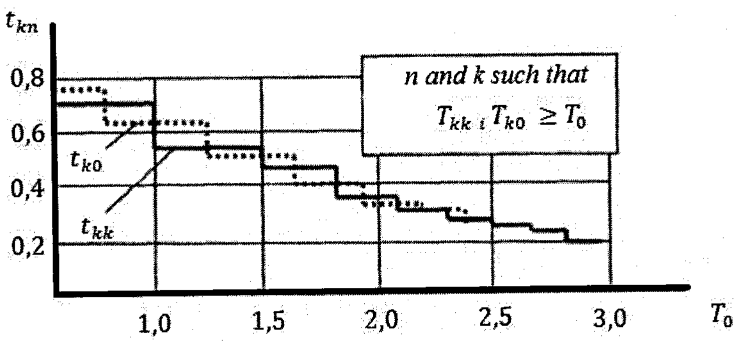

Fig. 4.12. Graph of t_{kn} dependence from T_0

For example, if $T_{11} = T_{20}$ and $t_{11} = t_{20}$ we transfer to the equations:

$$p = 2 - \sqrt{\frac{2-\alpha}{1-\alpha}}, \quad p = \frac{\sqrt{\alpha(3+\alpha)} - 2\alpha}{1-\alpha}.$$

The curves corresponding to these dependencies (Fig. 4.13), share the region of possible values α and p within four sub-areas, for each of them is executed one of the specified in Figure 4.13 pairs of inequalities.

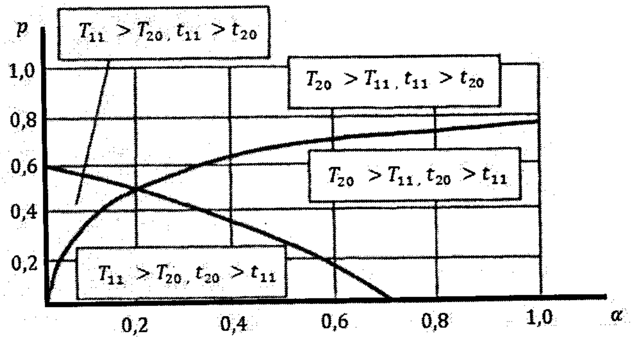

Fig. 4.13. Graph of p dependence from α

Reliability of renewable systems elements leads to some extra costs. Therefore, at construction of renewable systems it must be striven not only to increase the average life time of elements but also to reduce the overall costs S_{kn}, caused by unreliability of the system elements. In this case, as a best method for improving the reliability it should be considered a method that minimizes these total costs.

We may assume that that the failure of both two and more elements is not possible and the time for elimination of failure is small, compared with time to failure. Then the replace of elements is a recovery process and its intensity tends to T_{kn}^{-1} and does not depend on the element reliability function. Thus, we can assume that during the time t will happen tNT_{kn}^{-1} failures (N – number of elements).

The cost of removal of one failure is $C_{kn} + \beta$ where C_{kn} – the cost of the replaced item, β – costs caused by stopping, reducing the efficiency of the system, loss of data and so on. Then the total costs caused by unreliable elements of this type, are

$$S_{kn} = \frac{TN}{T_{kn}}(C_{kn} + \beta) \qquad (4.3$$

where T – service life of the system.

Graphs of functions S_{kn} for different values P and α are shown in Figure 4.14. From the graphs, it follows that there exists an optimal multiplicity of redundancy, in which S_{kn} takes the minimum value. It may be advisable to backup both trained ($S_{kk} < S_{k0}$ at β = $p = 0.7$ and $\alpha = 0.01$) and untrained ($S_{k0} < S_k$ at $\beta = 8$, $p = 0.6$ and $\alpha = 0.2$) elements.

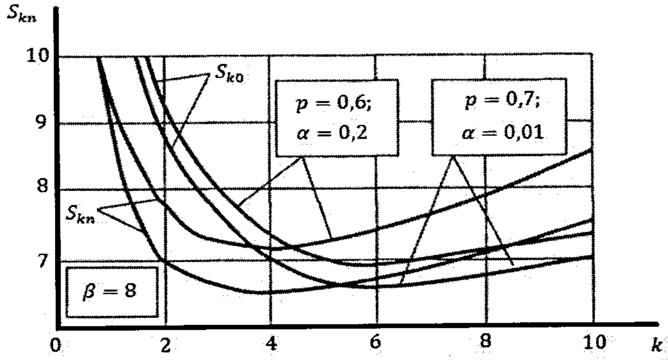

Fig. 4.14. Graph of total costs S_{kn}

It is not always possible to use backup in order to ensure the reliability of the components while the training of elements can be carried out almost always. In this regard, it is necessary to ascertain the feasibility of trained elements for systems renewal insuring. It is obvious, that to increase reliability through training of elements is meaningless if $S_{11} > S_{10}$ or:

$$\frac{\alpha}{p(1-\alpha)} > \beta \tag{4.38}$$

In Figure 4.15 is given the family of curves $p = \frac{\alpha}{\beta(1-\alpha)}$ where each curve in the plane (p, α) separates the region of possible values α and p into two sub regions – the top and bottom.

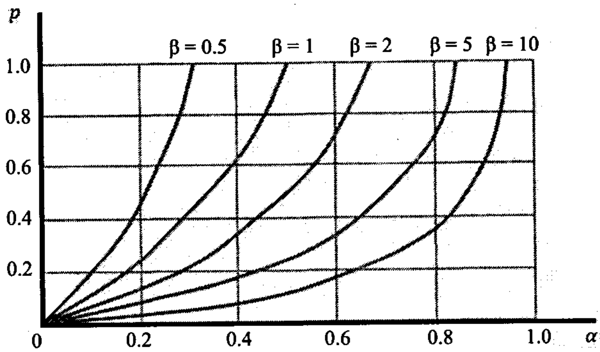

Fig. 4.15. Charts of curves family $p = \frac{\alpha}{\beta(1-\alpha)}$

For the plane of points (α, p) from the lower sub-region is implemented the requirement (4.38), this indicates that the use of trained elements for such data values α and p is inappropriate.

At construction of reliable information systems are used various methods to improve reliability, including redundancy methods that lead to a corresponding increase in hardware expenses. Thus, to increase average uptime at loaded reserve in 1.5 times, it must be used one basic and one backup object. Further increase in the average uptime in 1.5 times (it is then 2.25 times) requires four backup objects ($1 + 1/2 + 1/3 + 1/4 + 1/5 > 2.25$).

In correlation with this problem there emerges a problem of finding a reasonable level of reliability. With increase of reliability of an information system expenses C_e for its operation get higher. Increased reliability of the information leads to an increase in its costs C_0. Typical character charts of the expenditures dependence C_e and C_0 from the reliability P are shown in Figure 4.16. The total costs on production and operation of information systems have a pronounced extreme character and are minimal for certain values $P = P_0$ which has been named optimum reliability.

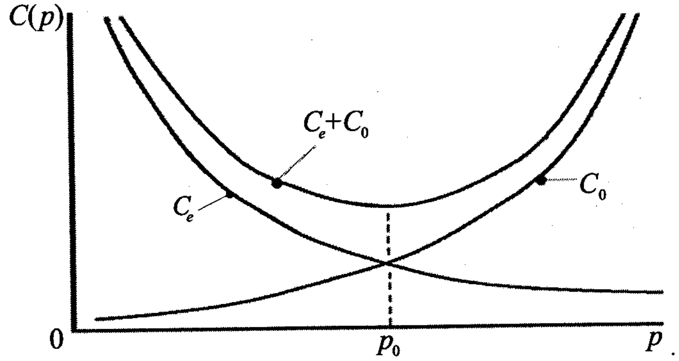

Fig. 4.16. Charts of typical character of the expenditures C_e and C_0 dependence from reliability probability P

In general, the optimal reliability is not so easy to determine. To solve the above mentioned problem it requires to build dependency C_0 and C_e from probability P for every case

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5. Information systems reliability characteristics definition

The following section provides the general methodology for the reliability characteristic of information systems determining. Below are presented the principal definitions:

- calculative characteristics of operation system reliability on priori data are the results c the direct problem of reliability solution,
- statistical well-ground reliability characteristics are based on the experimental data c measurement during operation and at testing, namely the results of the reliability invers problem solution.

The above mentioned methodology of information systems reliability characteristic calculation primarily uses as the basis for technical systems development and operation th results accumulated for several decades. Therefore, the results of this section mainly refle the calculations regarding information systems hardware reliability. Here are considered tw examples of individual characteristics analysis relevant to the performance of a system whic acquire one of indispensable functions and also describe the dynamic renewable technic systems efficiency changes. To the specificity of information systems software reliabilit characterization dedicated the special seventh section of this book [1–9].

5.1. Methodology and problems of reliability characteristics determination

The problem of ensuring the information systems reliability involves a variety of task including the following:

- development of theoretical methods for reliability analysis at the design stage,
- foundation reliability characteristics and its evaluation according test results,
- study of the physical processes that lead to the failure of equipment,
- experimental and constructional options for optimal contours design,
- development of effective informational package, including mathematical and softwa for the hardware and software operation ensuring,
- technology and organization of production,
- equipment planning and testing,
- system operation,

- implementation of program for improving system reliability, taking into account a significant number of operational factors, including education and training of technical personnel,
- economic issues and so on.

One of the major objectives of reliability foundations is to develop quantitative methods for the functions of reliability assessment, to define most efficient methods for the required level of reliability of the created information systems which are introduced into service.

Implementation of quantitative methods for the study of reliability provides:

- scientific substantiation of requirements for the newly established standards of engineering,
- designing of systems with the required level of reliability,
- planning volumes, timing and methods of research to achieve an assigned level of reliability,
- rationalization of ways to reduce economic costs and shorten time to systems development,
- selection and justification of most effective measures to ensure reliability during construction, design development, manufacturing and operation of systems,
- an objective assessment of the software and hardware operation in service,
- scientific evidence-based recommendations development to improve the systems functioning and methods of operation.

5.2. Calculative characteristics of system reliability

By the reliability of the object (a system. an item) is understood a property that provides an ability to conduct by these object some n essential functions ensuring specified properties according certain operating conditions and within the required time interval. Determination of reliability quantitative characteristics of these properties depends primarily on the fundamental point of view on the failure emerging – as on the event of object (item) transition from working state onto disabled.

The major mathematical apparatus in the theory of reliability is the theory of random functions and mathematical statistics.

Direct problem of reliability (a priori reliability analysis). The theoretical study and practical evaluation of reliability characteristics can be attributed to two phases which differ from each other regarding tasks, source data, and mathematical apparatus use.

At the first stage of system reliability study has to be solved the direct problem of reliability, which results in the reliability characteristics calculative estimation. There are several definitions on this reliability evaluation step: a priori reliability analysis, analytical methods for the system development reliability calculation, design assessment of reliability.

Priori reliability analysis is carried out at the design stage of a system, when at construction development are investigated several competing system block diagrams. Such analysis provides fully known a priori quantitative reliability characteristics for all items used. In fact, at the design stage with such a priori data, constructor has in possession only the data for those types of items that have long been in use. For novel items with no trustful quantitative characteristics of reliability, they can be estimated as similar to the characteristics of the reliability of the components that were used, or, on the base of experience.

Below we consider the steps for calculation of information systems hardware design reliability characteristics.

1. At the first step the calculation of reliability characteristics is based on the following assumptions:

- all elements of the system are equally reliable,
- the risks of failures of all elements of the system are independent of time, i.e. $\lambda_i = \text{const}$,
- stop working of any element leads to a failure of the whole system.

2. At the second step are calculated characteristics with take into account only the quantity and types of applied items influence on reliability which are based on the following assumptions:

- failure rates of all elements are independent of time, i.e. during the lifetime of the elements that build the system, there is no aging and deterioration, respectively $\lambda_i(t) = \text{const}$,
- all items operate according normally prescribed specifications,
- failure of system elements is a random and independent event,
- all elements of the system operate simultaneously.

In order to determine the system reliability we need to know:

- type of connection of elements for reliability calculation,
- types of elements that compose the system and the number of elements of each type,
- the value of items failure rate λ_i, for those that included in the system.

Thus, during the second step of reliability characteristic calculation it is sufficient to know the structure of the system, the range of applicable items and its quantity.

Approximate calculation of reliability is used in the following cases:

- during the test of the requirements for reliability, stipulated by the customer in the technical project for the system to be designed,
- at calculating of normative data regarding the reliability for an individual systems,
- in regard to determine the minimum level of reliability of the designed system,
- at comparing of assessments of systems individual reliability variations at the stages of preliminary and conceptual design.

Approximate calculation of reliability gives an indication on principle possibility to meet the requirements of system reliability.

At calculating the reliability of systems it is often needed to calculate the probability of failure of individual elements, multiply it, or to raise them into a power and remove the roots. For the values $R(t)$ close to unity, these calculations can be made with the satisfactory for practice accuracy according the following approximate formula:

$$p_1(t)p_2(t)...p_N(t) \approx 1 - \sum_{i=1}^{N} p_i(t),\ p_i^N(t) = 1 - Np_i(t),$$

$$\sqrt[N]{p_i(t)} = 1 - \frac{p_i(t)}{N} \qquad (5.$$

where $p_i(t)$ – the reliability probability of i-st module or system item.

Calculation of quantitative characteristics of reliability by the approximate formula does not give large errors for systems the probability of which failure-free operation is greater than 0.9.

This stage of reliability characteristics calculation is implemented in conceptual design stage after the development of principal electrical circuit system. This calculation allows determining the rational structure of system components and identifying ways to improve the system reliability at the stage of conceptual design.

5.3. Statistically based system reliability characteristics

The second phase of the study and evaluation of reliability characteristics for the designed and manufactured systems is carried out with the framework of the inverse problem of reliability solution, which is called the posteriori reliability analysis (experimental estimation). It is conducted on the basis of statistical analysis of experimental data on the efficiency and sustainability of systems obtained in the process of debugging, testing and maintenance. The purpose of reliability tests and performance data regarding reliability collection is the assessment of the system reliability and its components.

Such estimates are obtained by the methods of mathematical statistics on the results of data observations of usually limited volume. In this case it is assumed that the observations results are in fact the realizations of random functions, in some cases random variables, which are described by the probability distribution law of a given type with unknown parameters. The task of the inverse problem of reliability solution is primarily in the evaluation of unknown parameters based on observations and on further calculation using these estimations for the desired characteristics of reliability.

In practice for determining the reliability characteristics is used so-called calculation-experiment method. In determining the reliability characteristics with this method, the results are in fact placed into intermediate position between the results of direct and inverse problems of reliability solving, but they belong to the design characteristics, since they were determined grounding on the priori mathematical model.

Items of the system operate in diverse modes. This affects the system reliability either as a whole, or its individual components. Implementation of final calculation of reliability is possible then only at availability of data about the loading factor of individual elements and with the use of graphs of failures intensity dependence from electrical load, ambient temperature and other factors, that are, for the final settlement obligatory to identify the dependences:

$$\lambda_i = f(k_H, \ldots, T_H^{\,0}), \tag{5.2}$$

where different arguments are such as k_H – loading factor, $T_H^{\,0}$ – temperature in the system and other factors.

These dependencies are given in the forms of graphs or can be calculated using so-called correction factors for failure rates $\Delta\lambda_{K_H}$, $\Delta\lambda_{T_H}$ that allow clarifying the influence of various factors on system reliability.

To determine the system reliability characteristics it is required to identify:
– number of items, assorted by types and modes of operation,
– dependence of the intensity of failures of λ_i from the electricity supply modes and fro
given external conditions,
– structure of the system.

In general, the failure rate λ_i is determined by the following factors: the electric mode an element, ambient temperature, vibrations, mechanical shocks, linear acceleration, effe ing of biological factors (fungus, insects etc.), pressure, radiation and several other factor

Knowledge of dependence of failure rate λ_i from the effects of these factors is a mu for an effective use of elements in order to obtain the desired probability of its efficiency the system operation during time t.

The most influential factors are: the ambient temperature and the rate of change of t electric load, mechanical overload caused by vibration, shock and linear accelerations.

Failure of systems during its operation in the real conditions λ_i is equal to a norm failure rate λ_{oi} multiplied by the factor of influence α_i and the changes k_i.

Coefficient of influence $\alpha_i = f(T^0_H, k_H)$ includes the effect of ambient temperature T electric load, failure rate change coefficient $k_i = f(j, \varphi)$ – type of major mechanical load infl ence and the relative humidity of the air.

Calculation of reliability characteristics is introduced at the stage of technical design. becomes achievable at the creating of systems to fill in so-called information (maps) mod of the elements.

Reliability characteristics calculation is reasonable to conduct in the following order

1. *Formulating the concept of failure.* From the concept of system failure depends t choice of the number of elements and it must be considered also at reliability calculating. Oft in complex systems are used components, failure of which leads only to the deterioration some characteristics of the system (accuracy, the quality of the transition process, etc.). Failu of other elements leads to abnormal function of the system, i.e. in terms of the reliability these elements is not observable. Therefore, we should consider only those elements, failu of which leads to failure. Therefore, prior to calculating the reliability, it is essential to defi clearly what is it meant by a system failure, and then to choose the number of elements tl has to be taken into account when calculating the probability of correct operation or at t calculations of other quantitative characteristics of reliability.

2. *Charting of reliability.* For compiling the schemes for the reliability characterist calculating it is convenient to formulate so, that the elements of the calculation were present as the structurally designed systems. Feasible is variant, when in the systems calculation a presented items that do not always operate in the facility, but only on some part time. In tl case, it is practical to distribute such items according to the operation time into groups a to create for the calculation a group of independent elements. At the scheme of reliabil calculation it is advisable to indicate the operation time of each element.

3. *Determining method of reliability calculation.* On the basis of information (char of elements operation modes it can be determined load factors and according graphs a amendment formulas there can be calculated λ for all items.

If during system operation time element does not have constant failure rate, but there exist distinct time intervals during which the element failure rate is basically constant, then, for the calculation of reliability it is used so-called equivalent intensity failure rate of an item. Let assume, that the element failure rate during time t_1 is λ_1; for the period t_2 it is λ_2 and so on. Then the system failure rate of an item during time $t = t_1 + t_2 + \ldots t_n$ will be:

$$\lambda_{fei} = \frac{\left(t_1\lambda_1 + t_2\lambda_2 + t_3\lambda_3 + \ldots t_n\lambda_n\right)}{t}. \tag{5.3}$$

4. *Complying a table for system failure rate calculation.* To calculate the system failure rate can be used appropriate tables.

5. *There are calculated the quantitative characteristics of reliability.* These calculations are to be entered in the summary tables or are given in the form of graphs. Calculations are issued in a form of a technical report.

Despite the difficulties of data collection (difficulty is in observing at real conditions, quick moral aging), currently there is a lot of material on the reliability of various products. These data are combined and listed in the directories for the case of operation under normal conditions (e.g. $T_o = 20 \ldots 25$ °C relative humidity 50–70%, load factor $k_H = 1$). To take into account the actual conditions and the effects of various external factors there introduced correction factors. In the Table 5.1, as an example, are shown the values of the correction factors depending on the installation location for one of the classes of electronic equipment. Knowing the rate of k, we can estimate the intensity of items failures by the formula $\lambda = k\lambda_0$ where λ_0 – failure rate under normal conditions.

Table 5.1

Correction factors for military equipment

Operating	k
Specially equipped rooms	1
Fixed ground facilities	10
Ship	17
Terrestrial vehicle	25
Aircraft	150
Guided missiles	300
Rockets	900

For better determination of λ, in reality the factor k is multiplied on the correction factors k_3 which takes into account the effect of individual factors. The most important factors are temperature regime, the load and operating conditions of which for the equipment of industrial purposes are listed in Table 5.2.

Table 5.2

Corrections $k_i(i = \overline{1,7})$ for some conditions

Operating	$k_i(i = \overline{1,7})$						
Stationary laboratory	1.0	1.0	1.0	1.0	0.4	1.0	0.5
Heavy industrial	1.1	1.5	2.0	2.0	0.6	1.5	–
Terrestrial vehicle	1.5	2.5	2.5	2.5	1.0	2.0	1.2
Ground portable	1.7	2.0	2.0	1.5	0.8	1.5	1.0
Ship	2.0	2.0	2.0	2.0	0.8	1.5	1.0

In the inactive state the failure rate of systems is usually significantly less than in operating state. For fairly rough estimations, this ratio is 1 to 10, and for more precise estimations it is taken as: 1 to 30 for mechanical items, 1 to 80 for electrical components and 1 to 10 for electromechanical products which may include failures of electrical and mechanical origin (Tab. 5.3).

Table 5.3

Intensity of failures $\lambda \cdot 10^{-8}$ hours for the items in idle mode

Name of item	$\lambda \cdot 10^{-8}$	Name of item	$\lambda \cdot 10^{-8}$
Hydraulic Cylinders	3	Acid Batteries	0.6
Ball bearers	1.1	Mechanical Clutches	44.1
Axial fans	12.5	Film capacitors	45.0
Hydraulic Fittings	277	Magnetic core memory	0.002
Gaskets	1.1	Hard disk memory	14.8
Electrical heating devices	35.5	Electromagnets	30.0
Gearbox mechanical	14.6	Thermal relay	200.0
Variable capacitance capacitors	2.5	Variables resistors wired	16.3
Electric DC motors	22.0	Variables resistors general purpose	2.0
Electric AC motors	49.9	Switches for general purpose	2.1
Alternators	19.6	General purpose relay	3.2
Electromagnetic valves	19.4	Silicon transistors for general purpose	0.11
Hydraulic valves	99.0	Diesel engines	89.8
Pneumatic valves	21.4	Mechanical filters	3.5
Transformers electrical	1.2	Hydraulic Pumps	4.3

5.4. Characteristics of systems longevity

Here we turn to the models that characterize some concept of reliability – longevity, which is a property to support a system in operational state until the boundary maintenance condition – system repair onset. During the modeling of longevity, same as for reliability modeling, in general case we proceed from the fact that the object is characterized by a set n of output characteristics $B_1(t)$, $B_2(t)$, ..., $B_n(t)$ and its performance in operability area is described in the n-dimensional phase space. In this case, if $B_1(t)$, $B_2(t)$, ..., $B_n(t)$ are considered as independent properties, the efficiency area of each characteristic and the disability progress $B(t)$ is advisable to display in the coordinates $B(t) - t$, where the value B_{max} is limited to the area of this parameter disability. Analysis of system performance loss of all n parameters can be done using the system reliability assessment methods.

Next, we consider two examples that reflect the work of renewable systems that meet the most typical schemes conditions of operation, namely:

- system functions for a given period T_3 (e.g., 8 hours per day, 3 days a week, 10 days a month) for a given interval of time,
- system operates continuously till failure.

In both cases, after a period of continuous operation, there conducted recovery processes, maintenance and repair, i.e. the period of continuous operation alternates with time-intervals for restoration, maintenance and repair.

5.4.1. Example of disability of a system for a given period of its continuous operation

Here we consider an example for a given period T_3 is the time of continuous system operation, after which follows renewal work, including maintenance and repair (if required). The grounding of value T_3 is determined by functional purposes and by the features of the operating system. For the specific characteristics of the system we select one of the major characteristics of the system operation $B(t)$, which describes the system performance by one of the required functions. In general, the selected characteristic of system functioning will be described by a random process $B(\omega, t)$ and its implementations are the functions of time $B(t)$.

The implementation $B(t)$ is the output function characteristic of the system (characteristic precision performance, capacity etc.) and the tolerance to characteristics changing of $B(t)$ to B_{max} defines the system disability area borders.

Further we conduct analysis of changes in characteristics $B(t)$, mathematical model of which is a stochastic process $B(\omega, t)$ for two consecutive periods of system operation, namely at the j-st and $(j + 1)$-st periods with the corresponding time interval $t \in [(j - 1)T_3, (j + 1)T_3]$. The results of this analysis are shown in Figure 5.1 as a graphical illustration of characteristics $B(t)$ vs. time to failure t changing, and as an indication of system disability. At graph $B(t)$ plotting will be used specific data that are typical for information systems hardware operating.

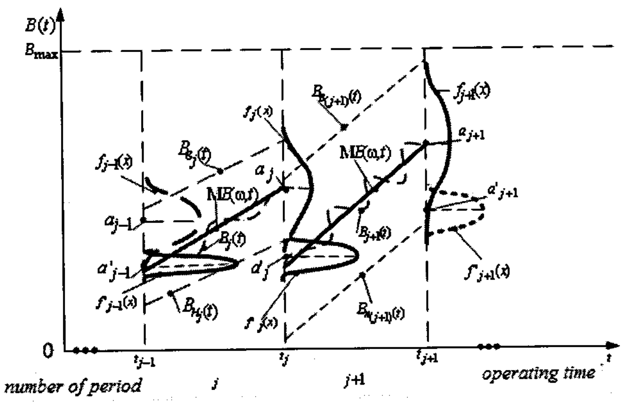

Fig. 5.1. Graph of characteristic $B(t)$ change vs. time to failure t for a studied system

In Figure 5.1 is shown a graphical illustration of system ability loss according functio $B(t)$ as of the characteristic of system functioning with a preset T_3 period of its operation whi performing the stipulated service. The graphs illustrate corresponding changes in the requir values of $B(t)$ as of the random process $B(\omega, t)$ implementations at the j-st and $(j + 1)$-st p riod of the system operation. Time intervals (recovery of maintenance, repairs) to impro the system reliability characteristics after a operation period in Figure 5.1 are not shown, the time since the end of $(j - 1)$-period of the system operation and of the beginning of t j-period are connected with each other. The graph (Fig. 5.1) shows only the total time failure t for the examined system as the sum of the operation periods.

1. First we analyze the implementation of $B(t)$ at a fixed moment of time $t_{j-1} = (j - 1)$ At this point there ends unbroken $(j - 1)$-st period of the examined system service a become known the statistic measurement values of implementation $B(t)$ of process $B(\omega,$ in the time interval $t \in [0, (j - 1)T_3]$. This assessments makes it possible to obtain the calcul tative data, namely statistical estimation of the distribution process $B(\omega, t)$ parameters a determine the theoretical distribution law $B(\omega, t)$ on the basis of the known statistical criter

Next, we shall consider the normal distribution of values for the process $B(\omega, t)$, assumi that such law in most practical cases becomes applicable because of the large number of rando factors actions at the formation of process $B(\omega, t)$. More detailed analysis of various facto action on the system reliability characteristics were considered earlier in the third section. the time moment $t_{j-1} = (j - 1)T_3$ the value of the process $B(\omega, t_{j-1})$ is described by a rando variable $\xi_{j-1}(\omega)$, probability density function of which is described by the normal law of for

$$f_{j-1}(x) = f(x; a_{j-1}, \sigma_{j-1}) = \frac{1}{\sigma_{j-1}\sqrt{2\pi}} \exp\left(-\frac{(x - a_{j-1})^2}{2\sigma_{j-1}^{\ 2}} \right) \qquad (5$$

where a_{j-1} – mathematical expectation (center of grouping),
σ_{j-1} – square root mean deviation.

Graph the function $f_{j-1}(x)$ vs. time t_{j-1} is shown in Figure 5.1 by dashed lines.

After the $(j-1)$-st period of system operation begins execution of recovery, maintenance and repairs processes in regular time intervals in order to enhance system reliability. After conducting recovery operations the examined characteristic $B(t)$ in time $t_{j-1} = (j-1)T_3$ is described by a random variable and therefore there starts a continuous j-st interval of system operating, usually with improved reliability characteristics, including characteristic $B(t)$.

Thus, before the beginning of the next j-st operation service period as a result of that values of the system characteristics will be partially restored, that will be manifesting in the shift of the grouping characteristics $B(t)$ apart from border values B_{max} and reducing the dispersion, i.e. $a'_{j-1} < a_{j-1}$ and $\sigma'_{j-1} < \sigma_{j-1}$. Full restoring of these properties is impossible, since at the long-term system service begins materialization of slowly flowing damage processes and other factors that lead to the reduction of safety margins.

Considering the effect of a significant number of factors that are involved in the formation of characteristic $B(t)$, including fast-action processes, probability density function of the random variable $\xi_{j-1}'(\omega)$ after restoring will be described by Gaussian law (normal distribution) of the form (5.4), i.e.

$$f'_{j-1}(x) = f(x; a'_{j-1}, \sigma'_{j-1}) = \frac{1}{\sigma'_{j-1}\sqrt{2\pi}} \exp\left(-\frac{(x-a'_{j-1})^2}{2(\sigma'_{j-1})^2} \right),$$

with parameters a'_{j-1} and σ'_{j-1}.

Graph of $f'_{j-1}(x)$ for the time moment t_{j-1} is shown in Figure 5.1 with a solid line.

2. Can be made analysis of characteristics changes $B(t)$ in the time interval $t \in [(j-1)T_3, jT_3]$.

With increasing time to failure t at the j-st interval of system operation, compared with the system service on $(j-1)$-st interval we may choose the following character for normal distribution law parameters change:

– the mathematical expectation

$$a_j(t) = a'_{j-1} + \gamma_j t, \quad t \in [0, T_3] \tag{5.5}$$

– square root mean deviation

$$\sigma_j(t) = \sigma'_{j-1} + \delta_j t, \quad t \in [0, T_3] \tag{5.6}$$

where the values of the time coefficients γ_j and δ_j characterize the change of specified parameters by the linear dependence of time to failure t and therefore they essentially reflect the rate of its change over time.

During j-st operation period the influence of average speed degrading processes is manifesting in shifting the mean $B(t)$ characteristic along the interval $[(j-1)T_3, jT_3]$ (in the graph the mathematical expectation system $\mathbf{M}B(\omega, t)$ changes process characteristics are considered according (5.5) as linearly dependent from the time to failure t within the reported j-period of operation) and also in increase of the dispersion characteristic $B(t)$. At the end of j-st operation period the distribution density function characteristic $B(t)$ at the time moment $t_j = jT_3$, as of a random variable $\xi_j(\omega)$, represents itself as a density function of a normal probability distribution of form (5.4), but already with other parameters, such as with

$$f_j(x) = f_j(x; a_j, \sigma_j).$$

Parameters of such probability distribution law taken into account the linear relationshi type (5.5) and (5.6) are defined as following:

– mathematical expectation

$$a_j = a'_{j-1} + \gamma_j T_3, \qquad (5.7$$

– mean square root deviation

$$\sigma_j = \sqrt{\sigma'^2_{j-1} + (\delta_j T_3)^2} \qquad (5.8$$

where γ_{a_j} and $\sigma_{\gamma j}$ are accordingly the average characteristics rate change $B(t)$ and the mea square root deviation of the characteristics change rate during the fixed time $t = jT_3$.

System reliability reserve at the j-st operation period is defined as the ratio of maximu allowable value of the characteristic $B(t) - B_{uj}(t)$ to its maximum operating value, i.e.

$$k_r = \frac{B_{\max}}{B_{\max} - B_{u_j}(t)}, t \in [(j-1)T_3, jT_3] \qquad (5.9$$

where $B_{uj}(t)$ and $B_{ej}(t)$ – corresponding upper and lower limits (borders) of values for th random process $B(\omega, t)$ confidence interval at the continuous j-st period of system operatio realizations $B(t)$ with the specified normal distribution densities of form (5.4). Graphs of th confidence interval $B_{ej}(t)$ and $B_{uj}(t)$ limits in Figure 5.1 are shown by dashed lines. There als used the specified linear dependence of the parameters a_j i σ_j according expressions (5.5) ar (5.6) vs. the time characteristics $B(t)$.

Graph of probability distribution density values for the process $B(\omega, t)$ at a time mome t_j is described by the normal distribution law $f_j(x)$ with parameters a_j i σ_j and it is shown wi solid line.

At availability of reliability reserve $k_r > 1$ regarding item gradual damage, the syste is considered secured, but at actual use it will be always in a danger of an early loss of pe formance due to the sudden failures, caused by external influences not associated with th system technical state.

For unbounded distributions, in normal case, the boundary conditions characteri tics $B(t)$ can be determined during the time intervals of continuous periods of the syste operation, for example, with a given probability ($P = 0.95$ at interval $a \pm 2\sigma$, or $P = 0.997$, interval $a \pm 3\sigma$), thus indicating about shifting some of a random process $B(\omega, t)$ realizatio into the specified area.

3. It can be conducted an analysis of changes in characteristics $B(t)$ within time inte val $t \in [jT_3, (j+1)T_3]$. At the time moment $t_j = jT_3$ there ends the j-phase of the system oper tion and therefore there arise changes of characteristic $B(t)$ as of disability at the performan of required function due to the time to failure t increase.

Before the beginning of the next $(j+1)$-st period of systems operation, similarly to th renewal work conducting, during j-st period of such systems the operation characteristi will be partially restored that will be manifested in the shift in the values of the groupi characteristics center off the border value $B_{\max}$ and also in reducing of dispersion, i.e. $a'_j <$ and $\sigma'_j < \sigma_j$.

So in the time moment $t_j = jT_3$ we will have a beginning of $(j + 1)$-st interval of system operation. Accordingly, by analogy with (5.4) the following probability density function is described by

$$f''_j(x) = f_j(x; a'_j, \sigma'_j) = \frac{1}{\sigma'_j \sqrt{2\pi}} \exp\left(-\frac{(x - a'_j)^2}{2(\sigma'_j)^2} \right).$$

Graph of this function at the time t_j is shown in Figure 5.1 with solid line.

With time to failure t increasing at $(j + 1)$-st interval of system operating, according analogous to the system operation, on $(j + 1)$-st interval, we obtain, as before, a linear dependence of time of the form (5.5) and (5.6), namely:

– mathematical expectation

$$a_{j+1} = a'_j + \gamma_{j+1} t, \quad t \in [0, T_3];$$

– mean square root deviation

$$\sigma_{j+1} = \sigma'_j + \delta_{j+1} t, \quad t \in [0, T_3],$$

where the numerical coefficients γ_{j+1} and δ_{j+1} describe accordingly, the rate of change of given parameters at the $(j + 1)$-st period of system operation.

Graph of normal density distribution $f_{j+1}(x)$ during the time t_{j+1} for the parameters a_{j+1} i σ_{j+1} is shown in Figure 5.1 with solid line.

At the moment t_{j+1}, similarly to previous periods at beginning of the renewable work to increase system reliability and according to specification $B(t)$ we obtain $a'_{j+1} < a_{j+1}$ and $\sigma'_{j+1} < \sigma_{j+1}$.

Graph of functions $f'_{j+1}(x)$ with the parameters a'_{j+1} i σ'_{j+1} is shown in Figure 5.1 with a dashed line. This is very same law of the distribution process $B(t)$ that determines the time moment t_{j+1}, of the $j + 2$-st period when system operation begins.

These changes in the characteristic $B(t)$ that determine the performance of the system will reduce the reliability of the whole system during time t (at increase of j).

As a result of significant number of factors action, beginning from a certain time to failure, the value of which is defined when the characteristic $B(t)$ reaches the top of the border of the edge level B_{max} as of the corresponding system state, the reserve stock of the system reliability is exhausted and emerges a real risk of resource rejection.

Established resource of system T_{0B} according characterization $B(t)$ and at the considered operation mode is defined as the nearest multiple of the values of T_3 time to failure at which there yet is maintained the reliability margins ($k_H > 1$). Similarly is set the *fixed resource* of systems, in which the boundary state is considered unacceptable because it results in major economic losses, threatening service personnel security or leads to harmful effects on the environment.

Average of the system recourse $\hat{T}_{0B}$ according characteristics $B(t)$ is defined as the nearest multiple of the value of T_3 time to failure at which the mathematically expected value of the process output parameter changes $\mathbf{M}B(\omega, t)$ has not yet reached the threshold level for B_{max}.

The considered method of system operation makes it possible to plan in advance the measures of maintenance and repair. However, during the first operation period, when the reliability margins are still large enough, these measures are primarily preventive in its na-ture. System capabilities for continuous operation in these cases are not used in full, whicl is the main drawback of such operation mode.

5.4.2. The system work efficiency loss till failure

Here we consider the following examples of system operating but in another mode. How-ever, the same as in the previous example (section 5.4.1), for a specific characteristic her were chosen $B(t)$ as fundamental characteristic of the system functioning, namely – one o required n functions performing.

For a number of technical systems, including informational, a regulated period of continu-ous operation normally is not stipulated. In this case the operation lasts to its failure or to th *time to failure*, which corresponds to a given probability of failure-free operation. Afte the failure the system is regulated, provided other maintenance, including repairs tha restore the performance of the system, and the system can continue to function normally. T eliminate the undesirable consequences of failure there are often designated more stringer border values for specification $B(t)$, achieving of which by a specific implementation of $B(t)$ a of a random process $B(\omega, t)$ is conventionally recorded as a failure. In other words, ther formulated arbitrary limits (borders) for achieving by the characteristic $B(t)$ value $B'_{max} < B_{ma}$ where B_{max} corresponds to the rejection of the system according the characteristic $B(t)$. Ra-tionale value of B'_{max} is determined by the distribution law of a random process $B(\omega, t)$, a a mathematical model of characteristic $B(t)$ for a given probability of failure-free operatio

This mode of system operation makes it possible to give a typical example of the hard-ware information systems (further simply system) operation.

For such example the mathematical model of characteristic $B(t)$, which is formed und the influence of a large number of random factors is described by the vector random proce

$$\mathbf{B}(\omega,t) = \left(B_1(\omega,t),\ldots,B_j(\omega,t),\ldots,B_n(\omega,t)\right), \omega \in \Omega \qquad (5.9$$

where each component of the vector is the stochastic process $B_j(\omega, t)$ describing the chara-teristics $B(t)$ during the j-st time interval of continuous system operation. At the end of th interval occurs j-st system's failure. In some cases, the components of the random vect (5.9) can acquire the same for all type of sequence k-dimensional distribution function, b the parameters of such distribution laws for each j-st interval are different, compared to oth intervals. This is confirmed by actual technologies of renewable works to enhance the syste state efficiency.

If there are n numbers of failures, then the system had completely worn out its technic resources and further it is removed from the service.

In practice, at the operation of such systems, it follows that, depending on the failu rate $\lambda(t)$ there can be selected three areas of time to failure t (in more detail this analysis given in section 1.5.1) which as presented here:

- the initial operation period (during debugging, breaking in) of a systems when re-ance $\lambda(t)$ monotonically decreases to a certain level,

– during normal system operation, while in some cases there is met a condition

$$\lambda(t) \equiv \lambda = \text{const},$$

– the terminal operation period (degradation time) of a system is characterized by a reduction in performance due to degradation, accumulation of damages, wear etc., and the $\lambda(t)$ dependence monotonically increases.

On the basis of the technical systems operation research results, there is published a large number of scientific works on the systems reliability. In the Figure 5.2 is shown graphical illustration of characteristic $B(t)$ changing vs. time to failure t as for corresponding realizations of the random process $B(\omega, t)$ within the system operation continuous interval. Time intervals of the renewal work after a system failure are not shown in Figure 5.2 because the total accumulation of continuous intervals of the system determines the total time to failure of a repairable system. The variation of implementations $B_j(t)$ for each continuous j-st interval of the system operation is selected by default for real operations of technical systems.

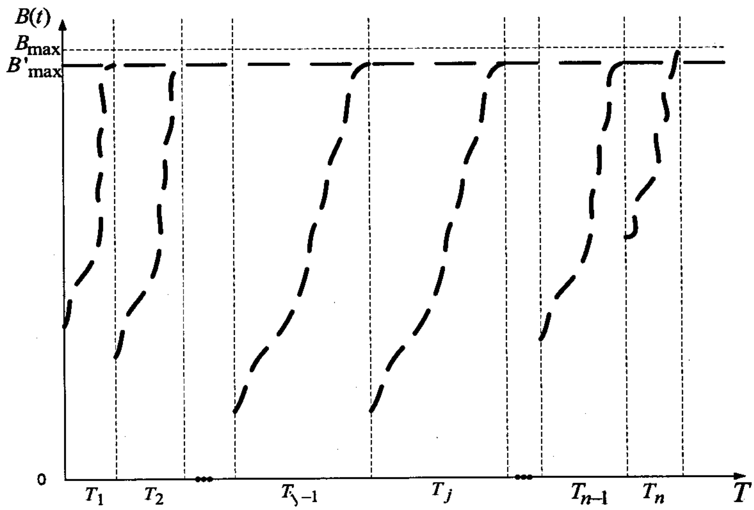

Fig. 5.2. Graphic illustration in the characteristic changes $B(t)$ for repairable system dependence from time to failure t

Here we consider separately the grounding for the given in Figure 5.2 characteristics $B(t)$ change graphs.

Length of time intervals sequence for the unbroken system operation between failures is described by the random vector

$$E_n(\omega) = \left(\xi_1(\omega), \ldots, \xi_j(\omega), \ldots, \xi_n(\omega)\right) \tag{5.10}$$

where each random variable $\xi_j(\omega)$ at the fixed time points is determined by the corresponding values of the random process $B_j(\omega, t)$. Obviously, the distribution law for a random variable $\xi_j(\omega)$ can be determined by known laws of distribution process $B_j(\omega, t)$.

Implementation of the random vector (5.10) is a deterministic vector of time intervals length of form

$$\tilde{\mathbf{T}}_n = \left(\tilde{T}_1, \ldots, \tilde{T}_j, \ldots, \tilde{T}_n\right), \tag{5.11}$$

and the sum of the components of this vector gives opportunity to determine the time to failure implementation for the examined system

$$\tilde{T}_0 = \sum_{j=1}^{n} \tilde{T}_j, \quad T_j > 0 \tag{5.12}$$

For each actual system the T_0 is a realization of a random vector (5.10).

If the laws of distribution for each component $\xi_j(\omega)$ of the random vector (5.10) are known, then taking into account the independence of the said component at time to failure interval (random variables are defined by no crossing time intervals – its determination areas), then the average system time to failure is determined by the following formula

$$T_0 = \sum_{j=1}^{n} \int_{-\infty}^{\infty} t f_j(t) dt,$$

where $f_j(t)$ – one-dimensional density of the probability distribution of the random variable $\xi_j(\omega)$ which describes trouble-free operation during the researched j-st interval of operation.

Figure 5.2 illustrates that the length of j-st operation time interval for a particular examined item is defined by the time of realization $B_j(t)$ at the moment of the random process $B_j(\omega, t)$ conditionally acceptable level $B'_{max} < B_{max}$ achieving. The last two numerical values are determined by the process $B(\omega, t)$ probability distribution law.

At the event when it is observed intervals T_j duration stability (or it is very small in this time scale), we get the simplest failures flow case for a repairable system with parameters $\lambda = \frac{1}{T_j} = \text{const}$.

Such case corresponds to the period of normal operation, when the level of accumulated wear damage is not yet so high that to effect essentially on the technical state of a system but the major contribution to the failure makes a sudden refusal. An effect of sudden failure determines the level of failures flow parameter during normal operation. At the subsequent system operation (at total time to failure increase) because of the influence of slow damage processes, the failure flow parameter begins to increase monotonously, commencing the transition to the final operation period, which is characterized by a progressive degradation of the system. The advantage of this operation mode compared with the method with the prescribed duration of continuous operation lies in the usage of the performance field of the system and in its potential opportunities for failure-free operation at each j-st interval of operation.

The disadvantages of this method are:

- incomplete determination of maintenance and repair planning due to significant fluctuations in the period of continuous operation $\tilde{T}_j$,
- the need for continuous surveillance of system technical state in order for timely determination of implementations $B_j(t)$ exit out of conventional boundaries;

- high probability of a real failure, as during each interval of operation is implemented the entire system reliability stock, and characteristics change rate $B(t)$ after reaching realizations $B_j(t)$ of level B'_{max} can be significant.

These examples are typical for information systems hardware restoration and reflect the typical cases to determine their reliability characteristics.

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6. Information systems reliability testing

In this section are presented results concerning reliability insuring obtained at testin of mass production items – elements, units, modules of technical systems, which have bee accumulated during more than fifty years of testing experience. These results are used fo the hardware of information systems reliability testing.

The offered material is devoted to objects reliability testing, the topic is regarde as complex scientific and engineering problem including the subsequent points: alread known schedules for testing, methods of laboratory and accelerated trials, typical errors a organization, registration and the initial testing data statistical analysis, basics of reliabilit characteristics measurement.

The problems of information systems software reliability will be discussed in the chapte seven [1–10].

6.1. Briefly about objects testing on reliability

The purpose of reliability of various purpose hardware (objects) testing is to determin (by computation or evaluation) its real (statistical, experimental) reliability characteristic One of the major integral characteristics among the sets of reliability characteristics is th probability distribution law application in order to describe a facility fail-safe operation.

In the information systems, such fail-safe operation characteristic combines bot hardware-software systems and programming faultless operation.

Theory and practice of facilities testing for reliability basically has gained extensi experience for the technical means of mass production. There were obtained important resul on reliability at monitoring of parties (series) of mass production objects. Thus, the reliabilit control for a batch of *N* objects, which after the testing the reliability of the sampled volur of *N* party items will be put into exploitation can be described as following.

According results of samplings tests of *N* party of objects it is required to check tw statistical hypotheses, namely:

- hypothesis H_0 – the results of reliability tests meet specifications and the batch of objects can be passed into service;
- hypothesis H_1 (alternative) – the results of reliability tests do not meet the specification the batch of *N* objects is rejected and is not passed onto service.

At the decision making there can emerge two types of errors:

1) error of I-st type – hypothesis H_1 is accepted, but in reality applicable is the hypothesis H_0,
2) error of II-nd second type – adopted hypothesis H_0, but in fact it takes place the hypothesis H_0.

Probability of the first type error in reliability theory is called the *risk of the manufacturer (supplier)* and denoted with the letter α. Probability of the second type error is called a *risk of the customer* and is indicated by letter β. Depending on the functional purpose of the party of objects the value α is selected mainly from the set $\alpha \in \{0.01; 0.02; 0.05; 0.1\}$. It should be also noted that at objects testing for reliability it is used method called Bernoulli trial scheme: the object operates with probability p, the object does not operate with probability $(1-p)$, i.e. the test of objects on reliability concerns in compliance with its two states: one with probability p and 0 with probability $(1-p)$.

We consider detailer the facilities testing for reliability.

The objects tests on reliability are experimental (full-scale test technique) methods according the results of which it can be obtained the solution of the following problems:

- to determine the actual objects reliability characteristics,
- to develop recommendations for ensuring and improving the reliability of the tested objects.

There entered the following definitions.

Reliability tests – examinations that are conducted to determine or to control the performance reliability according the particular requirements.

Assessment of objects reliability characteristics during the test should be conducted with a given accuracy (i.e., for a given level of relative accuracy) and with given veracity. Similar requirements are applied to the control tests.

Control of testing on reliability – tests that are set to monitor reliability performance.

Testing planning is the selection of such assessment characteristics, awareness of which should be considered as the primary test purpose. This choice is determined primarily by the physical significance of the proposed characteristics and also by those urgent tasks, which are found in the investigated objects or at operation of preceding issues objects.

Moment in time, at which occurs a rejection, cannot be specified in advance, it is random. It is known about the stochastic nature of the parameters that determine the reliability of an object, since their values vary from one object to another and so this change is not ordered, accidental. This fact leads to the necessity to evaluate on the basis of tests the required numerical distribution reliability characteristics, as well as the existing links between them, including the application of the relevant provisions of mathematical statistics, concerning the problems the set of which was formalized before trials.

The normal test for reliability – reliability testing methods and conditions which provide the essential amount of information during the time (the term) which is specified in the service recommendations.

Data about quality characteristics in compliance to the mandatory, given by operating conditions and within the required time (operating time) obtained in the alternate form ("respond

– does not respond", "success-denial") are used to assess and control the reliability. In some cases, these objects tests are named "the scheme of Bernoulli trials".

Reliability control – test of object compliance to the specified requirements for reliability.

Determinations of reliability can be made both by an experimental method (inverse problem of reliability) and with the statistical modeling (direct problem of reliability).

Full-scale testing (integrated, public) is to be held on the objects manufactured according the documents submitted to serial production and operation, according requirements maximally close to real operation conditions. These tests provide the most complete picture of the performance and reliability of an entity and of the object as a whole.

Determinant reliability testing – testing to determine the reliability characteristics with a preset accuracy and reliability.

Determinant tests are classified

1) according the nature of reliability characteristics assessment, which is:
   - test, to determine point estimations of the mean values (parameters) of reliability characteristics (mean time to failure, mean life cycle, average recovery time etc.),
   - point assessment due to the characteristics of these tests is the arithmetic mean of the characteristics which is observed at homogeneous party objects sampling trials,
   - tests to determine the confidence interval of possible values of the reliability characteristics with a given confidence probability which covers the mathematically expectation value of these characteristics;
2) according the output data:
   - direct test based on the use of information about the facility failure,
   - tests based on the use of indirect signs of failures (overheating, vibration levels, noise etc.);
3) by testing plan for reliability.

This classification we will consider more detailed in the next section.

6.2. Existing schedules for the objects reliability testing

In the schedules for the reliability tests (Tab. 6.1) are defined terms and volumes of testing, namely there required [1, 7–9]:

- the number of objects (products) for testing,
- the sampling data volume,
- total time of testing,
- requirements regarding the renewal or non renewal of items that failed during testing.

Tests planning variants are indicated with three symbols:

- the first character indicates the number of the tested object,
- second character indicates the presence or absence of a replacements (or recovery) at testing of the objects that were rejected,
- third character indicates the length of testing time.

Table 6.1

Tests reliability planning terms and definitions

Term	Definition
1. Test plan [*NUT*]	Testing plan according which were tested simultaneously *N* objects. Objects that failed are not to be restored or replaced. The test is stopped at the end of the trials time or at the time to failure *T* for every object that did not fail
2. Test plan [*NU r*]	Testing plan according which were tested simultaneously N objects. Objects that did not fail are not then restored or replaced. The test is stopped when the number of objects that failed reaches *r*. At $r = N$ applied plan [*NUN*].
3. Test plan [*NU* (*r*, *T*)]	Testing plan under which simultaneously are tested *N* objects. Objects that did not fail are not be restored or replaced. The test is stopped when the number of objects that denied, reaches *r* or at the end of testing time or the time to failure *T*
4. Test plan [*NRT*]	Testing plan according which were tested simultaneously *N* objects. Objects that failed during the tests are replaced by new ones. The test is stopped at the end of trials time or during the time to failure *T* for each of *N* objects. ***Remarks.*** Each of *N* objects occupies a definite position (stand, test pad etc.) for which exists the further defined duration *T* of tests regardless of changes of items that failed at this position.
5. Test plan [*NR r*]	Testing plan according which were tested simultaneously *N* objects. Objects that failed during the tests are replaced by new ones. The test is stopped when the total amount of the objects at all positions reaches *r*.
6. Test plan [*NR* (*r*, *T*)]	Testing plan according which were tested simultaneously *N* objects; the objects that failed during the tests are replaced by new ones. The testing is stopped when the amount of objects at all positions reaches *r* or at the end of the trials time, or during the time to failure *T* for each position, depending on what condition is met first.
7. Test plan [*NMT*]	Testing plan according which were tested simultaneously *N* objects. After each failure an item is restored. Each item is tested until the end of trials time or to the time to failure *T*.
8. Test plan [NMT_Σ]	Testing plan according which were tested simultaneously *N* objects. After each failure an item is restored. The test is stopped at the end of the total for all items trials time or during the time to failure T_Σ.
9. Test plan [*NM r*]	Testing plan according which were tested simultaneously *N* objects. After each failure an item is restored. The test is stopped when the total number of failures for all objects reach *r*.
10. Test plan [$NM (r, T_\Sigma]$	Testing plan according which were tested simultaneously *N* objects. After each failure an item is restored. The test is stopped when the total number of failures for all objects reaches *r* or at the end of total for all objects in trials time or during the time to failure T_Σ, depending on what situation is met first.

Table 6.1 cont.

Term	Definition
11.Test plan $[NU(r_1, n_1), (r_2, n_2), ..., (r_{k-1}, n_{k-1}), r_k]$	Testing plan according which were tested simultaneously N objects. Objects that failed by the period of tests are neither restored nor replaced. After appearing of r_1 failures during trials are rejected n_1 objects that did not fail, after appearing of r_2 failures from tests are removed n_2 objects that did not fail etc., the test is stopped after the emerging of r_k failures.
12. Test plan $[NU (T_1, n_1), (T_2, n_2), ..., (Tk_{-1}, n_{-1}), Tk]$	Testing plan according which were tested simultaneously N objects. Objects that failed at the tests are not to be restored or replaced. At the end of the trial time or the time to failure T_1 from the testing are removed n_1 objects that did not fail (if number of objects that are did not deny exceeds n_1, otherwise the test is stopped) etc., the test is stopped after the ending of the trial time or during the time to failure T_k.
13. Test plan $[NUz]$	Testing plan according which were tested simultaneously N objects. Objects that denied at the tests are not to be restored or replaced. Every object is tested during operating time z ι, where $z_\iota = \min (t_\iota, \tau_\iota)$, $\iota = 1, 2, ..., N$; t_ι – time to failure of ι-st object; τ_ι – operating time before withdrawing of a working facility from the trials.
14. Test plan $[NU\ S]$	Testing plan according which were tested simultaneously N objects. Objects that denied at the tests are not to be restored or replaced. In compliance with the total trials time or with time to failure and the number of failures at any time, it is made a decision on recognition, or continuing the culling of tests. The tests are stopped at making a decision.
15. Test plan $[NRS]$	Testing plan according which were tested simultaneously N objects. Objects that denied at the testing replaced by new items. According the total trials time or time to failure and the number of failures at any time it is made a decision on recognition, or continuing the culling of tests. The tests are stopped by making a decision.
16. Test plan $[NMS]$	Testing plan according which were tested simultaneously N objects and after each failure object is restored. According the total trials time or time to failure and the number of failures at any time it is made a decision on recognition, or continuing the culling of tests. The tests are stopped by making a decision.

where:

N – sampling volume,
U – not renewable and not replaced when tested in the event of object failure,
R – renewable, but replaced at testing in case of object failure,
M – renewable at testing in case of the object failure,
T – time of trials or operating time to failure,
r – number of failures of objects that failed,
T_Σ – the total trials operating time or time to failure,
S – decision making at successive trials.

In some plan schedules the objects that did not reject are removed before the trials, beforehand. The need for this can occur for several reasons, for example, due to the failure of those components, the reliability of which was not explored in order to reduce the trials length. This effect, which leads to the termination of the trial before the object failure, called "censoring".

6.3. Laboratory tests of objects reliability

Laboratory tests on the objects reliability are held in the laboratory conditions.

To laboratory tests belong the testing which conducted in the laboratory on the test bench, i.e. on a technical device designed for installing the tested object into the specified conditions, creating there the action factors reflecting the information and process control implementation by the tests and (or) by object for testing, or by the testing site location, i.e. at the site designated for the testing in the conditions close to the required and enabled with the indispensable technical means of testing.

Laboratory tests are divided into autonomous and complex.

The main objectives of the autonomous tests are:

- design documentation for running work and operation of individual objects in the conditions close to the real checking,
- documentation adjustment and quality control of production facilities testing,
- identification and elimination of unreliable items and unacceptable operation modes of mechanical, electrical, electronic, electronic components and its elements,
- determining the limits (boundaries) of working capacity, the performance conformity assessment of the examined objects according the specification requirements and on the test results,
- correction of design documentation for the objects that conform only to comprehensive tests is conducted according the results of these tests.

To the independent testing must be subjected all created and upgraded facilities that are at finalizing stage and also the borrowed objects for which were changed the operation conditions, in anticipation of that there will be accomplished the whole list of testing.

Comprehensive (complex) testing is carried out at mutual working out of several examined facilities for the compliance with technical specification.

Evaluation of reliability characteristics enables:

- determination of actual values of reliability characteristics,
- monitoring of object compliance to the requirements specified.

As a result of planning is determined the required amount of testing and the normative evaluation; it is the decisive rule according which it is made the resolution about the object compliance or non-compliance to the requirements specified.

6.4. Accelerated testing of objects on reliability

Accelerated testing for reliability – a test at which the level of the acting load is selected higher than the level of the load under normal conditions in order to reduce the time required to monitor the load characteristics of the object or for its increase during a specified time.

Note that the selected accelerated trials should not change the basic types of faults, the nature of failures occurrence and its comparative advantages.

Accelerated tests are based on the intensification of the processes that cause failure or damage. At the accelerated tests is conducted a planned increase in the rate of the facility disability in order to reduce the trials time terms, compared with normal tests, i.e. tests, methods and conditions of theirs conduction intended for obtaining an essential amount of information in the same period as stipulated in the normative technical documents and according the operation modes for the given object.

The main characteristic of accelerated tests is the acceleration factor – the number, that indicates in how many times the length of the accelerated tests is less than the time length of the tests carried out according the prescribed circumstances and operating modes (normal test).

Acceleration factor can be calculated for the time to failure and by calendar time:

- *operating time acceleration factor* is the ratio of two time values required to obtain the same number of failures or deviations of parameters in the two samplings of equal volume at two different levels of stress and invariable nature of the occurrence of failures, failures types and its relative dominance,
- *coefficient of failure rate acceleration* – the ratio of failure rate obtained during the accelerated tests to the failure rate obtained during normal reliability tests when both failure rates belong to the same period of the tested objects lifetime,
- *failure flow parameter accelerating coefficient* – the ratio obtained for two different levels of external operating factors in relation to the number of failures of restored facility that was tested during the time interval set according to the fixed term of object service.

Normal and accelerated tests results will be comparable, if the subjected to identity of the break nature, the reliability characteristics values obtained will be identical, i.e.

$$R(t_n) = R(t_a) \tag{6.1}$$

where $R(t_n)$, $R(t_a)$ – reliability characteristics according normal and accelerated modes respectively, while the temporal characteristics of these arguments satisfy the condition:

$$t_n = k_a t_a, k_a > 1.$$

At the exponential distribution for the failure-free operation probability the requirement (6.1) can be written as:

$$e^{-\lambda_n t_n} = e^{-\lambda_a t_a}.$$

Where λ_n, λ_a – failure rate at normal and accelerated testing regimes, respectively.

If the rate of acceleration on operating time is $k_a = \frac{t_n}{t_a}$, then we find that the failure rate in normal regime should be

$$\lambda_n = \frac{\lambda_a}{k_a}.$$

The basic principles of accelerated tests include:

– workflows compression,
– extrapolation in time,
– range of loads limiting,
– increased frequency of operation cycles,
– principle of comparison,
– extrapolation on loading,
– principle of "breaking through",
– principle of "requests".

Practically any determined change of accumulated damage (for example, the value of wear downgrading) during the time t according an appropriate coordinate transformation, the stationary process of damage accumulation can be displayed in a linearized form, i.e. as a linear regression.

Using the method of least squares in this case is reduced to the calculation of the coefficients a and b in the linear regression equation of such type

$$\eta(t) = at + b. \tag{6.2}$$

The values of these coefficients are based on the test results for the damage values $\eta(t_i)$ (accumulated wear values) that meet certain discrete points in time t_i, for example, $i = \overline{1, m}$.

In general, the process $\eta(t)$ – the process of accumulated wear is random, i.e. $\eta(\omega, t)$, and the characteristics evaluations, and namely of the mathematical expectation and variance have to be calculated by averaging at the fixed t the ensemble of time synchronized implementations $\eta(t)$ of this process $\eta(\omega, t)$. Such averaging is applicable for both stationary and stationary not ergodic processes.

Thus the studied coefficients of the equation (6.2) can be defined according the formula:

$$a = \frac{\left(m\sum_i t_i\eta_i - \sum_i t_i \sum_i \eta_i\right)}{\left[m\sum_i t_i^2 - \left(\sum_i t_i\right)^2\right]}$$

$$b = \frac{\left(\sum_i \eta_u \sum_i t_i^2 - \sum_i t_i \sum_i t_i\eta_i\right)}{\left[m\sum_i t_i^2 - \left(\sum_i t_i\right)^2\right]} \tag{6.3}$$

where m – number of paired values t_i and η_i.

For each moment in time t_i is calculated statistical assessment of variance $\tilde{\sigma}_\eta^2(t_i)$ according the formula

$$\tilde{\sigma}_\eta^2(t_i) = \frac{1}{m_i - 1}\sum_{j=1}^{m_i}\left[\eta_j(t_i) - \tilde{a}_1(t_j)\right]^2,$$

where m_i – the number of experimental values obtained at time moment t_i (number of process implementation) j – number of experimental values obtained at time moment t_i ($1 < j \le m_i$), $\tilde{a}_1(t_j)$ – evaluation of the mathematical expectation (mean) of the process $\eta(\omega, t)$, averaged over all realizations of the process that occurs at the moment t_i, that is

$$\tilde{a}_1(t_i) = \frac{1}{m_i}\sum_{j=1}^{m_i}\eta_j(t_i).$$

For non-stationary process of damage (wear) the results of tests on variance are approximated by a quadratic dependence of the form

$$\sigma_\eta^2(t) = a + a_1 t + a_2 t^2.$$

If the value of a_2t^2 within the investigated interval of time is negligible, compared to a_1t, then the last addition can be neglected. If $a_1t_1 < a_2t_2$ then it is believed that the process $\eta(\omega, t)$ is characterized according the dominant influence of the initial quality of the samplings. Extrapolation (prediction) for this process should be carried out by testing of at least several objects.

Assessment of the resource can be obtained by testing even of single object, but of rather long time duration.

In practice we can assume that extrapolation along time gives a satisfactory durability assessment for the tests time length at least 40–70% of the object resource. This principle can be applied to the objects resource depletion processes of which are fairly well implicit. In general, the problem of extrapolating along time requires for its solving in each case three main assignments solving:

1) choice of the state equation that adequately describes the experimental results at the parameters changing tests,
2) study of the selected equation behavior outside the area of the experiment, which is reduced to the forecasting accuracy measurement,
3) selecting the volume of experimental data that provide reliable prediction for a given lifetime.

6.4.1. Practical guidelines at the accelerated tests conducting

For reference, as a result of numerous studies conducted in our country and abroad for the long-term durability of constructional metal predicting with its lifetime more than 100 thousand hours, there were suggested temperature and time dependence of type

$$T_p = aT^2\sigma^{-n}\exp(b - c\sigma),$$

where:

a, n, b, c – parameters which are constants and represent the individual characteristics of the material,

T – absolute temperature,

σ – voltage.

Reducing stress spectrum range is achieving by the rejection of a definite part of load that does not have a noticeable influence on the damaging tested object. Most of actual machinery and their elements are subjected to operating conditions specified by the action of random or repetitive stresses spectrum.

Particular case for stress spectrum range reducing is in using from all items, of which consists operating cycle, only those which conduct switch-in and switch-off, the only two components of motion – start and stop. The feasibility of this principle is based on the properties of some mechanisms to maintain high durability at constant motion, characterized by hydrodynamic friction. At the start or stop moments, there observed boundary or even dry friction, leading to a significant deterioration of working surfaces.

Based on the assumption that the constant movement does not lead to a significant deterioration, at the tests are reproduced starts and stops modes. The resource then is recalculated according the following formula, excluding the times of starts and stops:

$$T_p = N\bar{t}_z,$$

where N – number of start-stops, $\bar{t}_Z$ – the average length of the intervals between the start-ups, determined according operation conditions or according the calculation method based on the functional purpose of the tested object.

Tests according this principle give a slightly overestimated resource, but in most cases it is quite acceptable for practical use.

The principle of increasing the workflows frequency is based either on the frequency of the cyclic load growth or on speed of movement rise under tested element of object loading. It is assumed that the longevity of a product, expressed in number of cycles till border state does not depend on the application of the load frequency. The coefficient of acceleration is determined in advance, according the expression

$$k_n = \frac{f_n}{f_н}$$

where f_n, $f_н$ – frequency of the load application correspondently in the accelerated and normal tests.

The comparison principle is based on the facility trials in accelerated mode and recalculation the obtained results by using the known data about similar products operation.

Depending on the available information, an evaluation of objects reliability is made according three methods:

1) comparison of two objects longevity based only on the results of accelerated testing,
2) comparison the longevity of objects, subjected to trials in an accelerated mode, with the same mode object-analogue operation data tests results,
3) recalculation of data obtained at accelerated mode of objects testing and relating it to normal regime, provided that resource depends on the current level of loading.

The first method is used at exclusively comparative trials of two objects at finding of more lasting one. It is assumed that the object that had operated longer in the accelerated regime will have greater resource also at normal conditions. It is true, provided that the resource dependences from the acceleration level factor for the compared objects do not intersect in the range from nominal to increased levels of factors that force.

The second method assumes a presence of information about the object-analogue durability operation in accelerated and normal modes. Stipulated by this information, the acceleration rate coefficient, as for the analog, will be increased in the operating time up to borderline value obtained at the object testing in the accelerated mode. Such assessment is made with an assumption that the physical properties that determine the level of resource dependence from acceleration factor are similar, both for the new object and the object-analogue. This method is most suitable for testing of new mass production objects, regarding large information existing about the reliability of earlier versions.

The third method is based on recalculation the results about accelerated tests using the existing object resource dependency on the load.

The principle of "break through" is pretty universal principle for accelerated tests which is used at the mechanisms elements and structures resource testing for fatigue, wear and prolonged durability.

The principle of "break through" employs the facility damaging grade assessment by exposing this object during operational testing time to the impact of accelerated load mode in order to bring an item with this mode to a boundary state ("to break it through").

The principle of "queries" is used for facilities accelerated testing of engineering items, failures in which are caused by the gradual accumulation of wear damage, manifested in the monotonous change of the controlled output parameters (wear of limiting element, productivity, energy consumption etc.).

The trustworthiness of test results beside other factors (measurement error etc.) is determined by the correct choice of the type of a function responsible for the wear rate change from the level of accumulated wear of the object (or the corresponding function of the accumulation of wear vs. time). During this test results processing it is possible to correct the posteriori selected wear rate changes function, and in some cases also to start the development of new function (model) according the results of tests.

6.5. Tests measurement data organization, registration and pre-processing

The issue of testing, registration and pre-processing of information is a common and important for any kind of reliability tests.

At the testing organization it should be payed attention to the following factors:

– facility operation mode during testing (continuous or cyclic),
– the nature of external influences (mechanical, climatic, power etc.),
– objects of statistics registration,

- composition, duties and responsibilities of testing committee members;
- rules and procedures for facility performance monitoring,
- contents of information that is requisite to register for the reliability analysis and evaluation,
- forms of accounting documents to register operating time and failures,
- regulations for trials finishing.

It is known that the actual level of reliability of an object significantly depends on environmental parameters and facility operation mode.

Wide application has gained the method of sequential analysis which is especially useful at control tests. Typically, at control tests it is required to determine whether the time between failures of the tested system is greater than specified in the terms of reference (hypothesis H_0), or smaller than the given (hypothesis H_1). Then, setting the probabilities of acceptance or rejecting the hypotheses, consistently, for example, at specified intervals, the obtained data are analyzed. Thus, there are three situations:

1) to accept the hypothesis H_0 and reject H_1,
2) accept the hypothesis H_1 and H, and reject H_0,
3) to continue the experimental testing of hypotheses, since these defined data do not provide sufficient evidence neither for the first nor the second hypothesis.

Time T with this method is reduced by about half.

An essential feature for the experimental evaluation of reliability characteristics is large amount of data that must be fixed in each case, regarding objects operation disruption.

During the process of facilities reliability testing it must be recorded the following information:

- summary object's operation time and time from the moment of previous failure,
- position of breached item (serial and positional number of the object, which had failed),
- reasons of the rupture,
- consequences of the breach (full or partial disability, at what functions);
- type of breach (failure, change of settings etc.),
- measures against the breach (replacement, regulation etc.),
- data about the speed of switch and reserve control (for an object that has such provision),
- surroundings conditions during the moment of disruption (temperature, vibration, shock and other related phenomena, including manipulations by attendants).

Quite often abnormal function of objects, especially of prototypes, has no relationship to the "reliability" (triggering automatic protection fuse at voltage surges etc.). Therefore, a thorough check of all phenomena that accompany failure is very important for the test results primary processing proper qualifying.

Adequate primary information is provided by completeness and regularity of results records, as well as regarding the depth and objective analysis of failures reasons. It is important to bear in mind, that inaccurate original starting data cannot be improved even during a very careful subsequent statistical treatment.

6.5.1. Preliminary analysis of the test data

Obtained as a result of testing list of operation breaches is a combination of different types of situations, both by causes of failures arising, same as by their influence on the certain reliability index. Therefore, the test results processing should include as the first mandatory step, the pre-analysis. The main objectives of the previous analysis are the association and classification of information.

Within a limited volume of statistical information its quantitative homogeneity assessment by lone statistical criterion can be quite persuasive, since the primary resource of experimental assessments providing is the facilities manufacture conditions, engineering tests analysis and correspondent information about refusals classification.

Depending on the purpose of statistical information analyzing it is possible to classify it by different arguments – by influence on the object performance, by the method of recovery with respect to the specific reliability characteristics and so on. In terms of reliability tasks assessing, the critical are considered two groups of classified failures:

- by causes of emerging,
- in relation to the assessed reliability characteristics.

Groups into which may be classified the causes of failure are defined by measures that can improve the object quality.

There are following groups of failures caused by:

- quality of facility engineering development (designing),
- quality of technical documentation and tooling of production (technology),
- breach in the technology requirements made at manufacturing (production),
- operation of a facility in the modes and conditions not provided by the technical documentation (operating).

In addition to the controlled by information- telecommunication system objects, others than those listed above, it may be distinguished two groups of operation disorders, externally manifested as failures: algorithmic, program.

As a result of errors and deficiencies in programs, even very serviceable facility under certain conditions, becomes unable to perform its functions. For these failures it is in common, that they are identical for all objects in the event of arising of appropriate conditions.

At the failures classification in relation to the assessed reliability characteristics, all refusals are divided by to "accounted" and "unaccounted." To the unaccounted failures belong:

- caused by external influences, other than those provided in the technical documentation, as well as by the breach of the user's instructions,
- of prototypes, which the failure causes are eliminated at the reworking processes,
- associated with carrying out specific experiments,
- those which do not affect the assessed specific index.

Principles of failures classification regarding reliability characteristics are shown in Figure 6.1.

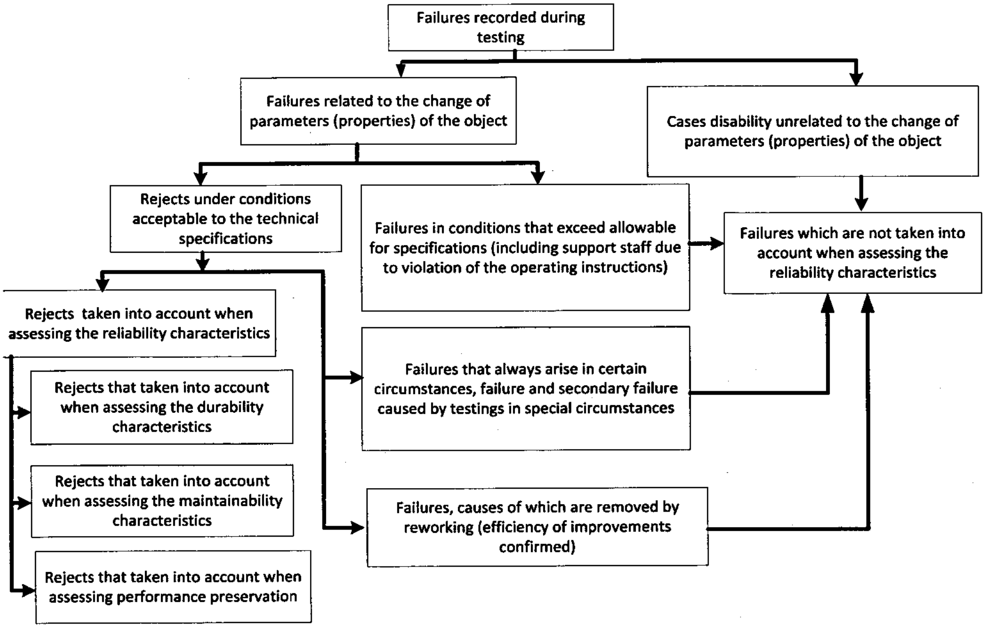

Fig. 6.1. Classification of facilities failures during testing

The considered methods of reliability characteristics determining belong to the class of so-called parametric methods. In this name is reflected the fact that the experimental data are approximated according the corresponding theoretical law of operating time between failures, and further, according these data are assessed the distribution parameters, and then the required reliability characteristics. However, such an approach to evaluating the reliability does not always provide the required reliability of the results, especially for the highly reliable facilities where at the prolonged tests may be obtained only 2 ... 3 rejections. From this data and with the accepted practice for accuracy, it cannot be determined the type of the distribution function for operating time between failures. In such cases for the refusal assessment it is more efficient to use nonparametric methods. Here is an example of using of one of these non-parametric methods for the tests data processing.

Example. Suppose that $t_1 < t_2 < ... < t_n$ are times till the first, second etc. failure. Then, in the neighborhood of the point t_i corresponding to $\lambda(t) = \frac{f(t)}{R(t)} \approx \frac{\Delta n(t)}{(N - n(t))\Delta t}$ where $\Delta n(t)$ is the number of elements that were denied during the time from t to $t + \Delta t$, we have:

$$\lambda\left(t_i - \frac{\Delta t}{2}\right) \approx \frac{n\left(t_i + \frac{\Delta t}{2}\right) - n\left(t_i - \frac{\Delta t}{2}\right)}{\left(N - n\left(t_i - \frac{\Delta t}{2}\right)\right)\Delta t} = \frac{1}{\left(N - n\left(t_i - \frac{\Delta t}{2}\right)\right)\Delta t}$$

or

$$\lambda\left(t_i-\frac{\Delta t}{2}\right)\Delta t=\frac{1}{N-n\left(t_i-\frac{\Delta t}{2}\right)}=\frac{1}{N-n(t_i)+1}$$

and further

$$\Lambda(t)=\int_0^t\lambda(t)dt=\sum_{i=1}^{n(t)}\frac{1}{N-i+1}.$$

The function $\Lambda(t)$ was called the leading function of the accumulated intensity or "the failures flow".

With the function tool $\Lambda(t)$ it can be defined another functional reliability indexes, for example, $R(t)=e^{-\Lambda(t)}$.

If to apply the function $R(t)$ in the form of the following series

$$R(t)=\alpha_1 t+\alpha_2 t^2+\alpha_3 t^3+\ldots+\alpha_m t^m \tag{6.4}$$

then, using the method of least squares the coefficients $\{\alpha_i, i=\overline{1,m}\}$ are determined according the following settings

$$M=\int_0^T\left(\Lambda(t)-R(t)\right)^2dt=\min,$$

where T – duration of the test, then it is possible to calculate a number of reliability characteristics, such as

$$T_0=\int_0^\infty e^{-R(t)}dt.$$

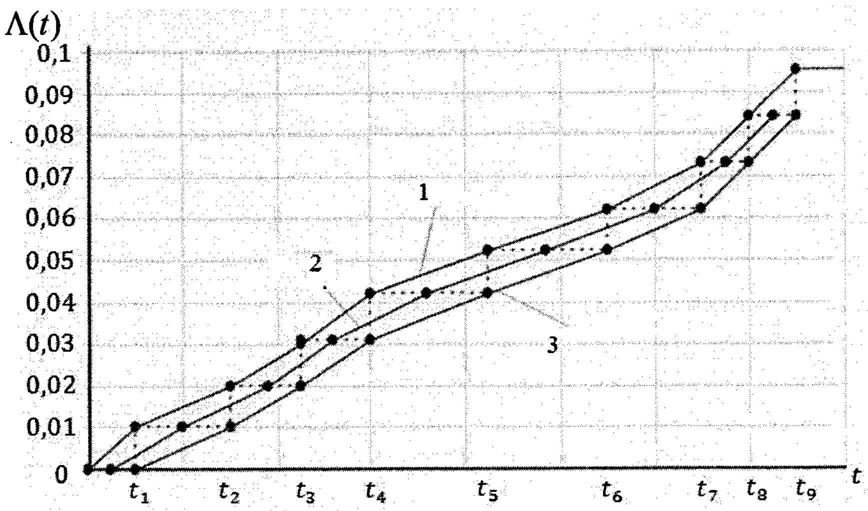

Fig. 6.2. Graph of cumulated failures intensity formation

Coefficients in series (6.4) can be found from the equations:

$$\frac{dM}{da_k} = 0, \quad k = \overline{1,m}.$$

We analyze the graph of the function $\Lambda(t)$, which is shown in Figure 6.2.

At the points $t_1, t_2, ..., t_n$ the function $\Lambda(t)$ has discontinuities (Fig. 6.2) and is defined by the following equations:

$$\Lambda(t) = \Lambda_0 = 0 \text{ when } t \in \{0, t_1\},$$

$$\Lambda(t) = \Lambda_1 = \frac{1}{N} \text{ when } t \in \{t_1, t_2\},$$

$$\Lambda(t) = \Lambda_2 = \Lambda_1 + \frac{1}{N-1} \text{ when } t \in \{t_2, t_3\},$$

$$\Lambda(t) = \Lambda_i = \Lambda_{i-1} + \frac{1}{N-i+1} \text{ when } t \in \{t_i, t_{i+1}\},$$

$$\Lambda(t) = \Lambda_{n-1} = \Lambda_{n-2} + \frac{1}{N-n+2} \text{ when } t \in \{t_{n-1}, t_n\},$$

$$\Lambda(t) = \Lambda_n = \Lambda_{n-1} + \frac{1}{N-n+1} \text{ when } t \in \{t_n, t_{n+1}\}.$$

where $n = n(T)$, $t_{n+1} = T$ – duration of the test (in which time $n + 1$ there was no failure). For $k = 1, 2, ..., m$

$$M = \sum_{i=0}^{n} \int_{t_i}^{t_{i+1}} (\Lambda_i - R(t))^2 dt, \quad \frac{dM}{d\alpha_k} - 2\sum_{i=0}^{n} \int_{t_i}^{t_{i=1}} (\Lambda_i - R(t))t^k dt = 0.$$

since $\Lambda_0 = 0$ then

$$\sum_{i=0}^{n} \Lambda_i \left. \frac{t^{k+1}}{k+1} \right|_{t_i}^{t_i+1} - \int_0^T R(t)t^k dt = 0.$$

hence we have:

$$\sum_{i=0}^{n} \Lambda_i \frac{t_{i+1}^{k+1} - t_i^{k+1}}{k+1} - \int_0^T \sum_{i=1}^{m} \alpha_j t^{k+j} dt,$$

and finally

$$\sum_{i=0}^{n} \Lambda_i \frac{t_{i+1}^{k+1} - t_j^{k+j+1}}{k+1} - \sum_{j=1}^{m} \frac{\alpha_j T^{k+j+1}}{k+j+1}. \tag{6.5}$$

For example, if to take $R(t) = \alpha t$, then $m = k = 1$, and from (6.5) we get:

$$\alpha = \frac{3}{2T^3} \sum_{i+1}^{n} \Lambda_i (t_{i+1}^2 - t_i^2).$$

The accuracy of reliability characteristics calculating depends on the number of series $R(t)$ whose coefficients are certainly sign-alternated. Since the function $\Lambda(t)$ is monotonic, then $\alpha_m > 0$.

Evaluation the calculations accuracy, for example T_0, can be done using the relation

$$\frac{T_{0,\,m+1} - T_{0,\,m}}{T_{0,\,m+1}},$$

where $T_{0,m}$ and $T_{0,m+1}$ are the value of T_0 at the approximation of $\Lambda(t)$ by series $R(t)$ of powers m and $m + 1$. Broken line 1 of graph $\Lambda(t)$, shown in Figure 6.2 connecting points (t_i, Λ_i) limits the $\Lambda(t)$ from above. Broken line 3, connecting the points (t_i, Λ_{i-1}), limits the $\Lambda(t)$ from below. Broken line 2 connecting points $\left(\frac{t_i + t_{i+1}}{2}, \Lambda_i\right)$ can be considered a conventional average average line that divides the area circumscribed by the lines indicated above, into two equal parts. The similar property has the broken line 2 which connects points $\left(\frac{\Lambda_i + \Lambda_{i-1}}{2}, t_i\right)$.

6.6. Typical errors at the test organization, registration and initial test data statistical analysis

General rules for tests conduction that contain clear and full instructions on all aspects of tests, are prerequisite for obtaining reliable data on reliability. The following are examples of some typical errors.

Deviations from the established rules of repair. This problem often manifests itself as a result of use of tools, utensils and replacement equipment, not designed to restore the facility and in the breach of the established by documentation facility recovery procedure. For example, instead of replacing the exchangeable object, which failed, with the spare item, someone starts its repair *in situ*. Rehabilitation of facility then may be significantly complicated or delayed. In this regard, it must be emphasized that in assessing the maintainability performance, the entire repair strategy projected by the developer in the service documentation along with the equipment repair and the kit of spare parts has to be subjected to the same trials as the object itself.

Deviations from the established modes of routine maintenance. Probable are also are deviations in the direction of both reducing and enlarging the restoration repair working procedures against stipulated in documentation. For example, some routine maintenance cannot be carried out due to a lack of time, or because of lack of appropriate staff. Obtained under these conditions results may differ substantially from those that were obtained in compliance with the officially installed system of maintenance.

Errors in the failures classification. These errors are most widespread. There are cases of distortions caused by purely departmental interests. For example it is often difficult to distinguish between accidental breaches of instructions by the attendants and the natural errors caused by ergonomic imperfections or by poor quality of maintenance documentation.

A common mistake is premature (not corroborated by subsequent tests) exclusion from the calculations such failures for which were made an appropriate rework (restoration, repair, replacement).

Another typical mistake is that into the group of unaccounted are recorded all failures detected during routine maintenance, arguing that maintenance works are intended to detect latent failures. At the same time into assessing the reliability are not included the failures accumulated in between routine periods, significantly overestimating all relevant safety assessments.

Common mistake is referring to the accounted some failures that have no relation to the assessed reliability characteristics. An example can be a stopping information system due to an error (but no improvement) of a program.

It should also be borne in mind, that accounting of certain definite failures depends on what specific reliability characteristic is assessed.

6.7. Fundamentals of objects reliability testing measurement characteristics

Measurement process is a combination of theory and practice (experimental, testing, operation) to characterize the reliability of an examined object. Basing on measurement results it is possible to quantify the actual reliability characteristics for an object of testing.

The following block diagram of the measurements process at testing of objects makes it possible to identify the major examined reliability characteristics directions for an object (see Fig. 6.3).

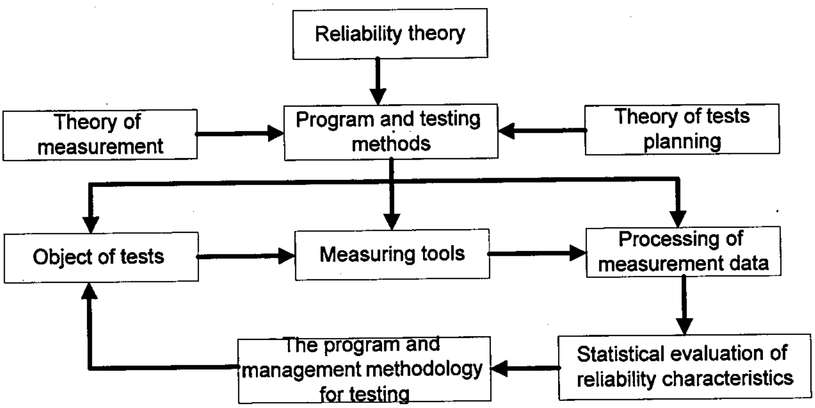

Fig. 6.3. Block diagram for the facility reliability testing using process of measurements

Determination of the objects reliability characteristics at testing is based on the measurement methods, and in a more general formulation of the problem, according the methods of metrology.

Metrology as the science of measurement is used at the objects reliability testing in its entirety. It is known that there are used all three major research areas of metrology:

– legal metrology (laws, international and national standards),
– measurement theory,
– applied scientific and technical problems of measurement.

Below we briefly discuss the major provisions specified in the areas of research in metrology regarding technical systems reliability testing.

First it can be considered a number of provisions done according the Ukraine metrology laws that are mandatory during a test.

6.7.1. Selected provisions from the law of Ukraine "On Metrology and Metrological Activity" for the objects tested for reliability

Law of Ukraine "On metrology and metrological activity" establishes the legal basis for measurement traceability in Ukraine, regulating relations in the field of metrology and aimed to protect citizens and the national economy from the effects of unreliable measurement results in a broad sense, including the measurement results at technical systems reliability testing.

Metrology – the science about measurement.

Measurement – a display of physical quantities with their values by means of experiments and calculations using special equipment.

Unit of measurement – a physical quantity of a certain dimension, which is adopted for quantitative measurement of homogeneous with it values.

Metrological activity – activity that is related to traceability.

Measurement methods – a set of procedures and rules, which displays the measurement performance results with a guaranteed precision.

Measuring instruments – technical utensils, which are used during measurement and have normalized metrological characteristics. Verification of measuring instruments is establishing the suitability of measuring devices that are within the state metrological supervision for its use on the basis of theirs metrological characteristics control.

Measurement results can be used if they are provided with the appropriate measurement errors estimations and uncertainty characteristics.

The objects of the state metrological control and supervision are: measuring equipment, measurement methods.

Measuring instruments can be used if they meet the requirements for accuracy established for these agents, under confident conditions of use.

Measuring instruments in operation are originated from mass production, repair and sales, are issued on rent, are backed by the state metrological supervision and subjected to verification.

Check up is also obligatory to the measuring equipment used in the state and other tests.

Organizations and individuals are required, promptly (including inter-verification intervals) present measurement devices for calibration.

During the metrological control of measurement traceability is checked:

- conditions and use of measuring instruments,
- relevance of measurement methods,
- accuracy of measurements,
- timeliness of measuring instruments submission for the check and calibration,
- compliance with the conditions and rules for verification and calibration of measuring instruments so that the measurements were conducted in accordance with authorized checking, certified by calibration and measurement laboratories,
- compliance to documental regulations on metrology.

Procedure for metrological control of measurement traceability, issuing regulations on the results of metrological control is defined by the central executive bodies, enterprises and organizations in compliance with the law.

6.7.2. Measurement methods theory in the problems of reliability characteristics quantifying

General terms. In the subject area of engineering metrology the reliability testing methods are used both in theoretical and applied techniques of scientific and technical issues of reliability characteristics measurement.

For reliability characteristics measurement are used the following methods:

- *direct* measurement method, at which the value of properties is determined (calculated) according the data obtained in direct measurement;
- *indirect* (indirect, cumulative or compatible) is a method of measurement in which the determined (calculated) values of properties are based on the results of two stages:
  a) determining by direct method other parameters values (as arguments of the studied characteristics) according obtained measurement data,
  b) as a result of computing the values of the studied characteristics according the known functional dependences of the values of the arguments obtained in the step (a).

According the results of statistical processing of measurement data are formulated statistical hypotheses, which are, as a rule, simple hypothesis: H_0 – the major hypothesis about the substantiation of the reliability characteristics mathematical model, the model which has been justified by a priori data of its research at the technical system design stage, and the corresponding alternative hypothesis H_1 – about not confirming to the major hypothesis H_0.

On the basis of statistical criteria (criteria χ^2, by Kolmogorov – D and Mises – ω^2 that were described in Section 1.3.3) will be adopted this or that hypothesis. In this case there are two mistakes which in different domains are named differently.

It was noted earlier that at statistical hypotheses checking emerge errors in acceptance of that or other hypothesis, which, in general, are defined as a corresponding conditional probabilities, so there is the following.

1. Conditional probability $\mathbf{P}(H_1/H_2)$ is the adoption of the alternative hypothesis H_1, provided that in fact there were confirmed the hypothesis H_0. Such probability in mathematical statistics is called error of type I, in the reliability theory – risk of producers and in radar theory – space omission and is designated as α.

2. Conditional probability $\mathbf{P}(H_0/H_1)$ is an acceptation of the major hypothesis H_0, provided that in reality there was confirmed the hypothesis H_1. Such probability in mathematical statistics is called error of type II; in the reliability theory – risk of the customer, and in the theory of radar – false alarm and is indicated as β.

In each case, the values α i β are justified basing on the functional purpose of a technical system, in most cases in practice $\alpha, \beta \in \{0.1; 0.05; 0.02; 0.01\}$.

One of the important research areas of statistical processing of measurement data reliability characteristics are statistical methods for errors measurement determining.

Statistical treatment of measurement data. Below we give the basic formula for the statistical treatment of multiple direct measurements data regarding the examined object reliability characteristics parameter, which is described by a random variable $\xi(\omega)$ with distribution function $F(x, \theta)$, where the unknown parameter θ is the target of measurement.

During the execution of multiple measurement experiments were obtained the sampling of measurement data

$$X_n = (x_1, x_2, ..., x_n) \tag{6.6}$$

which is a realization of the random vector:

$$\mathrm{E}_n(\omega) = \left(\xi_1(\omega), \xi_2(\omega), ..., \xi_n(\omega)\right),$$

identically distributed with the function $F(x)$ of independent random variables $\left\{\xi_j(\omega), j = \overline{1,n}\right\}$.

Spot evaluation. Statistical evaluations of the relevant points of a random variable $\xi(\omega)$ as of empirical moments are defined according the following formulas:

– the mathematically expected value (mean)

$$\tilde{a}_1 = \frac{1}{n}\sum_{j=1}^{n} x_j, \tag{6.7}$$

– variance

$$\tilde{\sigma}^2 = \frac{1}{n-1}\sum_{j=1}^{n}\left(x_j - \tilde{a}_1\right)^2 \tag{6.8}$$

where $\tilde{\sigma}$ – statistical assessment of mean square root standard deviation.

These statistical estimates $\tilde{a}_1$ i $\tilde{\sigma}^2$ are functions of the sampling (6.6), which are referred by the relevant statistics as of the functions of the sampling measurement data (6.6) and are described by random variables.

For statistical evaluation $\tilde{a}_1$ i $\tilde{\sigma}^2$ as of point estimations, it should be accomplished the following conditions, namely if statistical evaluation $\tilde{a}_1$ which is:

– *unsubstituted* if

$$\mathbf{M}\{\tilde{a}_1\} = \mathbf{M}\{\xi(\omega)\} = a_1,$$

– *consistent* (plausible, motivated) if there were an execution of the following inequality on the probability at a given $\varepsilon > 0$

$$\mathbf{P}\left\{\left|\tilde{a}_1 - a_1\right| < \varepsilon\right\} = 1,$$

– *effective,* if

$$\mathbf{D}\{\tilde{a}_1\} = \min$$

in the set of all possible other variances of the random variable $\tilde{a}_1$,

– *sufficient*, if for any other statistical evaluation a_1 of parameter $\hat{a}_1$ the random conditional value $\hat{a}_1/\tilde{a}_1$ has a distribution that does not depend on the parameter a_1, i.e. the appearance of evaluation $\hat{a}_1$ does not provide any new information for parameter assessment a_1 in comparison with what we have when using $\tilde{a}_1$.

These conditions for the statistical evaluation of the mathematical expectation $\tilde{a}_1$ should also be executed for the statistical evaluation of the dispersion $\tilde{\sigma}^2$.

Thus, at the measurements of unknown parameters $\tilde{a}_1$ i $\tilde{\sigma}^2$ of the distribution function $F(x, a_1, \sigma^2)$ we obtain statistical estimations $f\,\tilde{a}_1$ i $\tilde{\sigma}^2$ as a result of the statistical processing of the sampling (6.6) using formulas (6.7) and (6.8). Statistical evaluation $\tilde{a}_1$ in most cases is used as a measurement examined parameter θ and $\tilde{\sigma}^2$ which is the measurements data deviation variance statistical evaluation. Herewith $\tilde{\sigma}$ is appropriate statistical assessment of the standard deviation and is considered as measurements error.

Using the point estimations of the distribution parameters function $F(x, a_1, \sigma^2)$ for the examined reliability characteristics parameters at measurement approximately characterize the measurements results. Determination of bias value, variance, and in some cases, and also the distribution function obtained at measured statistical estimations $\tilde{a}_1$ i $\tilde{\sigma}^2$ characterize in more informative way the accuracy characteristics of the measurements results and they are the tasks of measurement theory research.

For example, statistical assessment of $\tilde{s}^2$ for variance $\mathbf{D}\{\tilde{a}_1\}$ is given by

$$\tilde{s}^2 = \sum_{j=1}^{n} (x_j - \tilde{a}_1)^2 \Big/ n(n-1) \tag{6.9}$$

where $\tilde{s}$ – mean square root standard deviation of the mean value of the parameter a_1.

Interval assessment. Such method of interval assessment of statistical processing of reliability characteristics data measurement, which was proposed by J. Neyman in 1935, is also known as *the method of confidence intervals.* This method is more advanced compared to the spot assessment and has obtained much more widespread use in practice.

Determination of the confidence interval is as following.

Confidence interval $[\beta_b, \beta_t]$ *of an unknown parameter* θ *is called an interval which with the confidence probability* γ *covers the true value of the parameter* θ, *i.e.*

$$\mathbf{P}\{\omega \in \Omega : \alpha_b(\omega) \le \theta \le \alpha_t(\omega)\} = \gamma. \tag{6.10}$$

The parameter θ is considered to be no accidental, and the borders (margins) of the confidence interval are random variables, respectively, $\alpha_b(\omega)$ and $a_t(\omega)$. Implementation of these random variables are β_b and β_t, the values of which we will receive on the results of statistical processing of measured data.

In practice, depending on the functional purpose of examined systems, the confidence probability γ to determine their reliability characteristics is chosen quite high, for example, $\gamma \in \{0.95; 0.99\}$.

For example, if according the results of the statistical analysis of measured data (6.6), relating the parameter θ we obtain the Gaussian distribution law $F(x, \tilde{a}_1, \tilde{\sigma}^2)$, and then we have the following confidence intervals

- $\mathbf{P}\{\tilde{a}_1 - 1.64\tilde{\sigma} \le \theta \le \tilde{a}_1 + 1.64\tilde{\sigma}\} = 0.9,$
- $\mathbf{P}\{\tilde{a}_1 - 1.96\tilde{\sigma} \le \theta \le \tilde{a}_1 + 1.96\tilde{\sigma}\} = 0.95,$
- $\mathbf{P}\{\tilde{a}_1 - 2.58\tilde{\sigma} \le \theta \le \tilde{a}_1 + 2.58\tilde{\sigma}\} = 0.99.$

Measurement errors. Practical value at the objects reliability characteristics measurements studies is primarily determined with the results and the errors of a measurement, which is a quantitative characteristic of the outcome of measurement deviation from the genuine.

Modern classification of errors is based on the following criteria:

– sources of formation,
– patterns or changes in the nature of the errors in time and/or space,
– forms or methods of measurement errors quantitative evaluation and their characteristics mapping.

Classification scheme of different types of errors is shown in Figure 6.4.

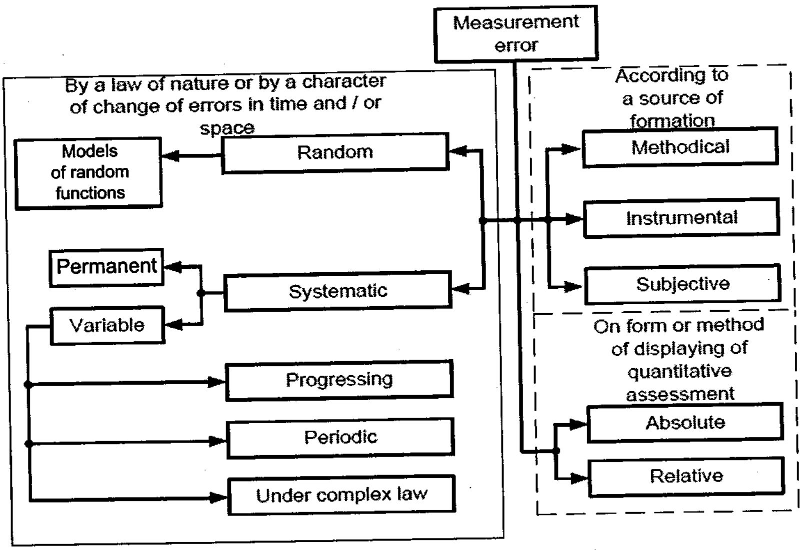

Fig. 6.4. Classification schemes of measurement errors types

We consider briefly the known types of the examined objects reliability characteristics measurement errors.

1. Sources, which include the selected method of measurement, analogous and hardware-software metering and research in the process of measurements allows distinguishing the following types of errors:

– *methodical,* which include:

- inadequacy of the mathematical model to the examined characteristic's real property at measurements,
- the chosen method of measurement, which is implemented in analog and hardware-software measurements and generates appropriate transformations errors, computing measurements of input signals, such as the use of continuous information transformation into digital signals, which are characterized by uncertainty of sampling vs. time and by quantization of the signal levels errors;

– *instrumental,* which is defined by the metrology and service, including accuracy performance, and by analogous or hardware-software measurements utensils;
– *subjective* (personal) that depend on the individual characteristics of researchers; such error is mainly characterized by the use of analog measurement means, but to some extent it is exposed at the use of hardware-software measurements.

2. Depending on the nature or the error information changes character in time and/or space are distinguished:
– *random,* which is described by random functions (random magnitude random vector, random process, vector random process) and is formed by a large number of factors in time and/or space actions, the physical nature of which is stochastic (random),
– *systematic,* which is described by deterministic functions, such as the mathematical expectation of a process random variable.

3. Quantitatively the characteristics of measurement errors are represented in two ways:
– *absolute* measurement error which is given by

$$\Delta X = X_m - X_c,$$

where X_m – measured and X_c – conditionally true value of the measured value, for example, if the measured value is described by a random variable $\xi(\omega)$, then as the X_c it can be used

$$X_o = a_1 = \mathbf{M}\{\xi(\omega)\}$$

or, if the measured value changes over time and its mathematical model is a random process $\xi(\omega)$, then as the X_m it can be used

$$X_c = a_1(t)\big|_{t=t_m} = \mathbf{M}\{\xi(\omega,t)\}\big|_{t=t_r},$$

where t_m – fixed moment of time measurement;
– *relative* error of measurement is defined by the ratio in relative units

$$\delta X = \frac{\Delta X}{X_c}$$

or in percentage

$$\delta X = \left(\Delta X / X_c\right) \cdot 100\%.$$

With the relative error of measurement is associated so-called *measurement accuracy.* Accuracy of measurement is defined according to the ratio

$$\gamma = \frac{1}{\delta X},$$

but the as quantitative description of measurement it is used rarely.

For example, if $\delta X = 10^{-2}$, then measurement accuracy is 10^2 and this should be used primarily at measurement results comparing.

The presented data about the measurement error are traditional (classical to some extent) results for the second half of the twentieth century research in metrology.

We briefly discuss the provisions of the "concept of uncertainty", which essentially enshrined today in the metrology, in the appropriate recommendations for the definition of the measurement results, offered into practice by International metrology organizations and are represented in the relevant Standards in Metrology.

The concept of measurement results uncertainty. The working group of the International Organization for Standardization (ISO), which included experts from various international metrological organizations has published a document GUM: 1993, which is used as "Recommendations" of internationally uniform rules for representing the uncertainty in measurement, standardization, at calibration of measuring technology, accreditation metrology services, test laboratories etc. This document became the de facto standard for measuring quality expression internationally and today there runs a process of harmonization of GUM:1993 with appropriate Ukraine standards in metrology.

Below we briefly discuss the essence of the measurement results uncertainty concept.

The very term "measurement uncertainty" means a doubt regarding the measurement probability result.

The fundamental difference of the proposed concept of uncertainty of measurement results from the traditional one, which was formed in the second half of the twentieth century, is as following: the reliability of a given measurement results is based on the experimental errors data obtained in the measuring process relying on the known characteristics of measuring instruments and the conditions of the experiment, but not using hypotheses about the precise value of the measured parameter.

Below we briefly discuss the methods of assessment and ways of measurement results uncertainty displaying.

By the method of assessment are distinguished:

- *category A* includes components that are evaluated by statistical methods of multiple measurements data processing;
- *category B* includes components that are assessed by other methods.

By means of display are distinguished:

- *standard uncertainty* of measurement result as the mean square root standard deviation;
- *the total uncertainty* as the standard uncertainty of measurement results, which is derived from the values of other variables associated with measured values;
- *expanded uncertainty* as interval assessment of measurement uncertainty, which is calculated as the product of the standard uncertainty by a factor of coverage, which depends on the type of distribution law and on the levels of probability coverage;
- *relative uncertainty* – the ratio of the standard, summated or extended uncertainty in respect to the measured value assessment.

Here are some examples of quantitative characteristics of uncertainty measurement results determining.

1. *Standard uncertainty of type A.* It is believed that these measured parameters θ as of the random variable ξ(ω) are defined according the sampling (6.6), i.e.

$$X_n = (x_1, x_2, \ldots, x_n).$$

According to (6.7) the statistical assessment mathematical expectation – the average – is calculated according the formula

$$\tilde{a}_1 = \frac{1}{n}\sum_{j=1}^{n} x_j,$$

and according (6.8) statistical assessment variance is

$$\tilde{\sigma}^2 = \frac{1}{n-1}\sum_{j=1}^{n}(x_j - a_1)^2.$$

Then the sampling (experimental) mean square root standard deviation $\tilde{\sigma}$ is *the standard uncertainty of measurement data, type A.*

According to formula (6.9) the standard uncertainty of the mean value type A is in $\sqrt{n}$ time less than the standard uncertainty of the measurement data type A.

2. *Standard uncertainty of type B.* This quantitative characterization of uncertainty is calculated for a given probability density function $f(x)$, for example, for:

– uniform distribution of $f(x) \in [b_1, b_2]$, the standard uncertainty of this data measurements type B is calculated according the formula

$$U(x) = \frac{b_2 - b_1}{\sqrt{12}},$$

– Gaussian distribution $f(x, a, \tilde{\sigma}^2) = N(a, \tilde{\sigma}^2)$ according formula

$$U(x) = \frac{L(p)}{k_p},$$

where $L(p)$ – the given confidence interval with a certain confidence probability p and k_p – coverage coefficient, so the value $k_p \in \{1.64; 1.96; 2.58\}$ is set according $p \in \{0,9; 0.95; 0.99\}$.

3. *Aggregate uncertainty.* Such quantitative characterization of uncertainty is calculated as a characteristic for indirect measurements.

It is considered as a given the n-dimensional function of arguments sequence $\{x_j, j = 1, n\}$ of type

$$y = f(x_1, x_2, \ldots, x_n). \qquad (6.11)$$

Herewith this sequence of quantities $\{x_j, j = \overline{1, n}\}$ are directly measurable quantities (direct method of measurement), by that measurements it is required to determine the standard uncertainty of n-dimensional function (6.11).

The total variance of n-dimensional function measured data, at situation of linear functions dependence from each of arguments x_j, and in case of mutually independent and also random arguments is determined according the following expression

$$\sigma^2(y) = \sum_{j=1}^{n} \left(\frac{\partial f}{\partial x_j} \right)^2 \sigma_j^2(x_j) \tag{6.12}$$

where $\sigma_j(x_j)$ – standard uncertainty of type A or by type B measurements data for each of the arguments x_j.

Then $\sigma(y)$ is *the total standard uncertainty of measurement data for the function (6.11).*

Determination the total standard uncertainty of reliability characteristics measurement data for the examined objects is quite a challenge, due to the following:

- n-dimensional function of the form (6.11) in most cases is a random field, and its arguments are random functions (random variables, stochastic processes), i.e., the dependence of the function (6.11) from the arguments in general case is also completely functional and statistical,
- definition of function (6.11) as well as of mutual statistical dependencies of its arguments for each examined object is a separate problem that can be solved using both measurement methods theory and methods of mathematical statistics,
- the combined standard uncertainty of the form (6.12) describes the simplest case of functional and statistical dependence of n-dimensional functions (6.11), although for more complicated cases are used other expressions, for example, for correlated random arguments x_i i x_j the calculation of the total standard uncertainty is conducted with the following formula

$$\sigma^2(y) \times (1-2) = \sum_{j=1}^{n} \left(\frac{\partial f}{\partial x_j} \right)^2 \sigma_j^2(x_j) + 2\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j} R_{ij}\sigma_i(x_i)\sigma_j(x_j) \tag{6.13}$$

where R_{ij} is mutual correlation momentum of the random arguments x_i i x_j.

4. *Expanded uncertainty.* Such interval measure of uncertainty is calculated according the formula

$$U = k_o \sigma(y) \tag{6.14}$$

where $\sigma(y)$ – the combined standard uncertainty (the examples of such calculation formulas are (6.12) and (6.13)), and k_o – its coverage coefficient.

For most practical problems the coverage coefficient k_o during construction of the confidence interval accepts values $k_o \in \{1.5, ..., 3.0\}$. For illustration, the values of coverage coefficient k_o for the Gaussian distribution at a given confidence probability p are given in Table 6.1.

Table 6.1

p	0.68	0.9	0.95	0.99	0.997
k_o	1	1.65	1.96	2.58	3

Thus, the expanded uncertainty of measurement data justifies the given confidence interval with a definite probability, and it covers the large part of the indirect measurements data function of form (6.11).

As it was noted above, the extended uncertainty is the most significant interval measure at the examined objects reliability characteristics quantitative measurements.

As a conclusion to the review of the presented material about measurement errors reliability characteristics at testing we shall give in Figure 6.5 some illustrative diagram of the relationship between traditional methods of error assessments obtaining and of a modern approach to their evaluation based on the concept of uncertainty.

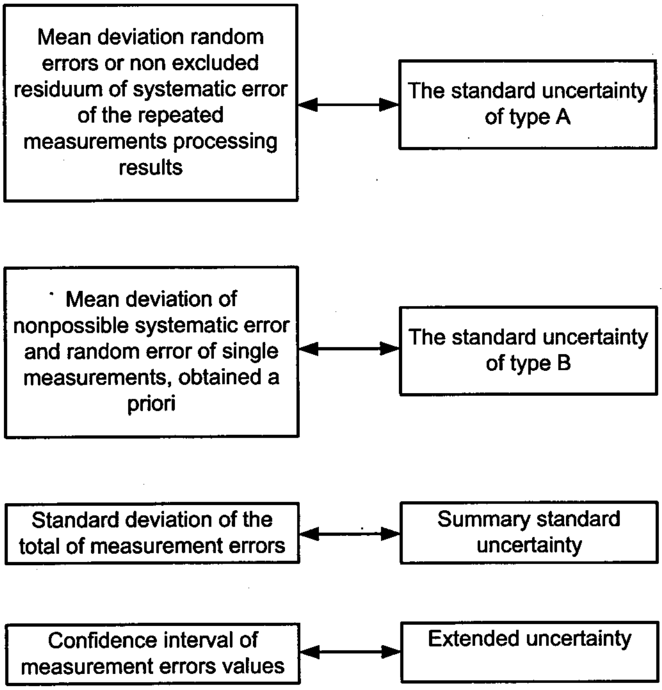

Fig. 6.5. Illustrative diagram on the relationship of error assessments obtained by traditional methods and by modern methods using uncertainty concept

Note that according the results of comparison of the traditional method and the concept of uncertainty in reliability characteristics measurement analysis it can be drawn the following conclusions:

- at application the concept of uncertainty it is fully used the data and the results of reliability characteristics measurement obtained by the traditional measurement methods;
- at today's standards on metrology, harmonized with international, in the majority of scientific publications on the concept of uncertainty are presented the methods of characteristics error recalculation in terms of measurement results uncertainty.

Indicators of measurement quality. For the qualitative assessments of objects reliability measurement characteristics it can be used the following types of measurements quality:

- *accuracy of the measurement results or the accuracy of the measurements* represent the measurement errors characteristics proximity to zero,
- *accuracy of measurement* represents the systematic measurement error characteristics proximity to zero,
- *convergence of measurement* represents proximity of properties measurement results obtained during the repeated testing under the same conditions,
- *reproducibility of measurements* represents the proximity between characteristics measurement results obtained at testing in different spatial locations, in different times, by different methods and means of measurement.

Thus, the use of metrology methods gives opportunity to obtain (to calculate) on the basis of statistical treatment of measured data the quantitative measures of performance and reliability characteristics and to determine their accuracy characteristics.

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7. Problem of software reliability

In this part are specified general characteristics of information systems software life cycle. Considered software application reliability questions and use of fail-safe ensuring programming. Also presented basic types of so-called virus programs that lead to abnormal functioning of information systems. In addition there presented some known models used for software debugging and operating.

It can be noted that the dynamism of software reliability research has speeded up significantly in the last period, and we can state the fact that its intensity is approaching, and in some cases is ahead of the information systems hardware reliability research intensity [1–14].

7.1. Process of software for information systems creation

The life cycle of the software (product) begins with the determining of its technical project development and ends at termination of its use.

There are following processes that executed during the life cycle of the software: five basic processes; eight supporting and four organizational processes.

Basic processes of life cycle structure consist of five processes that serve to the major constituents during the software life cycle.

The major constituencies are the subjects that initiate, develop, operate and conduct software maintenance. The main participants are customer, supplier, developer, operator and software maintenance supporter. The main procedures include the following steps:

- *order* – specifies the actions of the customer organization which order system, software product or software service,
- *supply* – establishes the supplier organization actions that provide the system software product or the software service,
- *development* – defines the actions of developer's organization that identifies and designs the software,
- *operation* – sets the actions of operator-organization that provides the (automated) services of information system in its current state to the users,
- *support* – determines the action of maintainer organization which provides services in support of the software, therefore manages modification of the software in order to maintain it in proper and operational condition. These processes involve the transfer and removal of software.

The support is considered as an integral part of the process that attends the latter; it has a clearly defined purpose and contributes to the successful software quality implementation. The process of support is applied and implemented in the proceedings according to its requirements. The structure of the software life cycle support process includes the following proceedings:

- *documentation* – defines the steps to register the information which was obtained during the life cycle course,
- *configuration* – defines actions regarding the software configuration management,
- *quality assurance* – determines the actions to acquire objective assurance that the software products and processes are ready to meet the specified requirements and adhere to its established plans.

As a method of quality assurance processes it can be used shared inspection, auditing, verification and validation:

- *Verification* – defines the actions of the customer, supplier or independent participant about verification software with varying degrees of depth, depending on the software features.
- *Validation* – defines the actions of the customer, supplier or independent participant regarding the obtained in the frameworks of programming project; software validation conducting.
- *Shared scrutiny* – determines the actions to assess the status and results of a definite action. This process can be applied by any two members, one of which (the party that review) evaluates actions of another party (party whose actions are reviewed) in a mutual discussion.
- *Audit* – defines actions to determine compliance with requirements, plans and contract. This process can be applied by any two members, one of which (the participant which checks) conducts an audit of the software or the actions of another participant (the participant which is being checked).
- *Problem solving* – identifies actions for analysis and removal of problems (including non-compliance), of any category of their nature and causes that were identified during the development, operation, maintenance or during other processes performing.

Organizational processes regarding the software lifecycle are used by an organization on order to establish and implement the basic structure which consists of life cycle interconnected processes and pertinent personnel, as well as for structures and processes continuous improvement. Their implementation is usually beyond the scope of improvement of specific projects and contracts, but the experience gained in projects and contracts can be used for organization performance improvement. Organizational processes include processes:

- *controls* – defines the actions regarding control, including project management during life-cycle,
- *infrastructure making* – defines the essential steps for the basic structure of the life cycle processes building,
- *foundation* – defines the basic steps which an organization (that may be a customer, supplier, developer, operator, developer or manager of a process), conducts in order to create, measure, control and improve the processes of life cycle that it supports,
- *training* – determines the actions to provide appropriate staff schooling.

7.2. Reliability of information systems software

Programs for modern information systems can accrue significant number (hundreds, thousands, tens or hundreds of thousands) of simple commands. For many reasons at writing programs it may be revealed the errors. In the environ of programmer's humor, they say, there is no software without bugs, but there are programs with errors not found. Blunders are detected at the stage of working out the programs, but to check the program totally according all possible modes is not usually viable, as result there is no conviction that all errors are found. There used a statistical approach to the process of errors detecting during the programming analysis.

Such process can be characterized according the function [10,12]:

$$\frac{f(t)}{R} \tag{7.1}$$

where $f(t)$ – number of identified and corrected errors per time unit in the program, which has R – number of commands.

$$\frac{f(t)}{R} = \frac{d\varepsilon_n}{dt} = \frac{\varepsilon_n(t+\Delta t) - \varepsilon_n(t)}{\Delta t} \tag{7.2}$$

where $\varepsilon_n(t)$ – number of identified and corrected errors during time t per one command.

Accordingly:

$$\varepsilon_n(t) = \frac{1}{R}\int_0^t f(t)dt \tag{7.3}$$

Function $f(t)$ can be determined experimentally during pilot testing of program by means of fixing the detected errors number. Problem of $f(t)$ definition is simplified if:

$$f(t) = \frac{\varepsilon_0}{\tau_0} e^{-\frac{t}{\tau_0}} \tag{7.4}$$

where ε_0 and τ_0 are parameters $f(t)$ which are determined during working out.

Then:

$$\varepsilon_n(\tau) = \frac{1}{R}\int_0^\tau f(t)dt = \frac{\varepsilon_0}{R}(1 - e^{-\frac{t}{\tau_0}}) \tag{7.5}$$

At $\tau \to \infty$ $\varepsilon_n(\infty) = \frac{\varepsilon_0}{R}$ or $\varepsilon_0 = R\varepsilon_n(\infty)$. From there it follows that ε_0 is the total number of errors in the program prior to testing. Since the testing process cannot subsist too lengthy then in the program always will remain some errors:

$$\varepsilon(\tau) = \frac{\varepsilon_0}{K} - \varepsilon_n = \frac{\varepsilon_0}{R} e^{-\frac{t}{\tau_0}} \tag{7.6}$$

where $\varepsilon(t)$ – the number of errors found per one command. If to anticipate that errors are uniformly distributed throughout the program, the occurrence probability of errors $P(t)$ during Δt will be proportional to the tempo pace δ of information system (that is the average number of commands changes per time unit) and to the number of errors left in the program, that is:

$$P(\tau)=\varepsilon(\tau)\delta\Delta t \tag{7.7}$$

Pursuing the analogy between the process of errors and failures of objects ($P(t) = \lambda\,\Delta t$) it may be concluded that the intensity of errors $\varepsilon(t)$ does not depend on time t but is determined only by the interval Δt at which it is estimated the probability of error. From there operation time till "failure", which is due to the error emergence in the program, will make:

$$T(\tau)=\frac{1}{\varepsilon(\tau)\delta}=\frac{R}{\varepsilon_0\delta}e^{\frac{\tau}{\tau_0}} \tag{7.8}$$

Analysis of $T(\tau)$ changes can serve as a basis for the program working-out operation timing τ choice, namely, the testing ends when the value $T(\tau)$ becomes large enough.

In case when it is possible to estimate material losses C_n via occurrence of errors in the calculations, then the operation time testing τ can be quantified as the following. If during time T_p of program operation, it fails $\frac{T_P}{T(\tau)}$ times, it will cause a total loss $C_n\frac{T_P}{T(\tau)}$. The process of program testing requires some time-consuming computations and other costs associated with it. If to mark C_0 the cost of a single time testing, then during time τ such costs will amount $C_0\tau$. Accordingly, the total loss C because of errors and costs for working testing of programs will be:

$$C=\frac{C_nT_P}{T(\tau)}+C_0\tau=\frac{C_nT_P\varepsilon_0\delta}{R}e^{-\frac{\tau}{\tau_0}}+C_0\tau. \tag{7.9}$$

From there:

$$\frac{dC}{dt}=\frac{-C_nN_P\varepsilon_0\delta}{R\tau_0}e^{-\frac{\tau_M}{\tau_0}}+C_0$$

or

$$\tau_M=-\tau_0\ln\frac{C_0R\tau_0}{C_nT_P\varepsilon_0\delta},$$

where τ_M – time of working out which will provide the minimum C.

In this case, when it is required to eliminate an error in the program it is advisable to use the "backup". Here particular problem is solved by several programs, each of them is developed by independent teams of programmers and in its basis lays various algorithms, furthermore, the results of programs computations are compared, and they are considered true if they match. Since the errors emergence in software is an improbable event, the occurrence of two or more of such events is practically impossible.

7.3. Use of fail-safe programs

Fail-safe programs are designed usually by frequent repetition of calculations at the levels of micro-operations, operations, commands, program modules or the entire program.

To improve reliability against the failures of the entire information system it is widely used method of repeated execution of programs at the level of program module. Its essence is that the program is split into several modules, each of them is executed twice, and the results are compared. If the results of the first and second calculations coincide, it is considered that the results obtained are true and then it may to proceed to the next step of (operational) calculations. At disagreement, the computation is repeated until the two received results will be the same. The substantional advantage of this method is its simplicity. At drawing up the program it is required only to provide the appropriate actions, the method does not require additional costs for hardware. The disadvantage of this method is in the time for problems solving more then twice growth, and in inability to detect errors caused by the failures.

Performance of information system at using the method of double execution depends on the number of modules into which is to be split the program. Indeed, the greater length of the modules determines also the fairly large probability of failures. So, instead of two, it will be required to repeat computations three or more times, which will increase the problem solution time. On the other hand, at small length of modules, most of time will be spent on comparing and recording the calculations results executed within individual program modules into the memory devices.

In this regard, there emerges a problem of finding an optimal number of modules into which a program should to be split, namely in such way that the time T_P for problem solving will be minimal. We introduce the notation: T – time for solving of problem at a single execution of the program; t – duration of calculation at a single module; $p(t)$ – the probability of no failure during time t. Then the ratio $\frac{T}{t}$ will determine the number of modules onto which should be divided a program. We can determine the probabilities of two-, three-, or even i times execution repetition for any program module. If the failures are independent events, then the probability that a given program module will be executed twice will be equal to the probability of no failure at the first and second executions, so that:

$$p_2(t) = p_1^2(t). \tag{7.10}$$

Subsequently, the probability $p_1(t)$ at fixed t will be denoted as p_1.

Similarly, g is the probability that in one of the two preceding calculations has occurred failure, but at the third computation was obtained correct result, that is:

$$p_3 = 2p_1^2(1-p_1) = 2p_1^2 q \tag{7.11}$$

where $q = 1 - p$. In general, p_3 equals to the probability that at the i-st and in one of the preceding calculations the failures were absent, and in the others, already passed, the failures were presented, that is:

$$p_3 = (i-1)\, p_1^2 q^{i-2}. \tag{7.12}$$

Thus, the average number of computing will be equal:

$$A = \sum_{i=2}^{\infty} p_i = \sum_{i=2}^{\infty} i(i-1) p_1^2 q^{i-2}. \tag{7.13}$$

It is easy to show that $\frac{A}{p_1^2} = \frac{2}{(1-q)^3}$. Hence we have $A = \frac{2}{p_1}$. Thus, the time spent on calculating will amount $\frac{2T}{p_1}$. Time T_3 which is required to conduct comparisons and to write intermediate calculations into the memory device, depends on the type of memory storage device used, on the number of intermediate results k and on the number of steps $\frac{T}{t}$ of the program, that is:

$$T_3 = \frac{T}{t} f\left(k, \frac{T}{t}\right) \tag{7.14}$$

where $f\left(k, \frac{T}{t}\right)$ – the average time of comparisons operations and of the recourse to the memory device for one module of program results recording. If we assume that $f\left(k, \frac{T}{t}\right) = \text{const} = a$ then:

$$T_p = \frac{2T}{p_1(t)} + \frac{T_a}{t} = T\left(\frac{2}{p_1 t} + \frac{a}{t}\right) \tag{7.15}$$

For some types of information systems it was experimentally found that:

$$p(t) = e^{-\lambda \cdot t} \tag{7.16}$$

where λ – the intensity of failures. In this case, T_p accepts the minimum value for t, which can be determined from the equation:

$$\frac{dT_P}{dt} = 2\lambda e^{\lambda \cdot t} - \frac{a}{t^2} = 0 \tag{7.17}$$

Thus the value of T_p can determine the optimal length of the program section and corresponding to it number $\frac{T}{t}$ of stations at which T_p will be minimal.

The cause of incorrect functioning of the information system may be also a presence in it so-called virus software programs designed to insert undue distortions into computations, deleting files and creating conditions for the abnormal functioning of information system.

In accordance to The Codifier of Information System Crimes of the General Secretariat of Interpol, viruses are classified to QD – the data information systems changes, within which they are classified as following:

- QDL – logic bomb,
- QDT – Trojan horse,
- QDV – virus of information system,
- QDW – worm of information system,
- QDZ – other's data changes.

Logic bomb – secretly inserts into a program a set of commands that should work only once, but starting at definite circumstances.

Trojan horse – provides an introduction into someone else's program of such commands, that allow conducting some foreign, not planned by the proprietor of program operations, while at the same time they preserve the general performance of the host program liability.

Virus of information system – a specially written programs that can "attribute" themselves to other programs (that is to "infect" them), to reproduce and give birth to new viruses to conduct various undesirable actions in the information system.

Worms of information system – special self-distributing software that makes editing data or programs of information system, without legal right, by transfer, introduction or spread through a network of information systems.

The share of errors or lockups of information system caused by viruses is about 10% to 30%. There are known more than 10,000 viruses and about 100 antivirus programs designed to combat them. There exist viruses (selfinscripted, polymorphic, macro viruses etc.) that can counteract the antiviral programs. One of such virus varieties implements "settlement" in the anti-viral program. Usually an antivirus program gives a signal of its infection if such event took place. Time required to cure a virus is on average from 15 to 30 minutes. The most dangerous virus is a virus that settles in the executive file. Most viruses "are working" apparently correctly and do not cause information system deadlocks. But among them are also those which completely erase the hard disk system areas or subdirectories of information files. In 90% of cases the viruses penetrate into information systems through the network. Normally local networks themselves do not distribute viruses. But users who work with memory devices which are damaged with viruses deliver to such network a lot of trouble.

The symptoms of information system infection with a virus are:

- increase of number of errors and lockups of information system,
- slow down the programs loading,
- problems (various slowdown and errors) with printer operation,
- drive lights flashing when it does not have to read/write,
- resizing the volume of executable programs, reducing the major available memory.

The volume shortest are destroying viruses; their size does not exceed 20 kilobytes. Most viruses have volumes up to 100 kilobytes or more. Recently a lot of trouble to the users deliver macro viruses.

Quality of antiviral program is defined according the following characteristics listed in descending order of importance:

- reliability and ease of operation (no technical problems, does not require a user's special training),
- number of all type viruses finding, an ability to scan the documents/spreadsheets files, packed files and also an ability of contaminated objects curing,
- speed of operation and a variety of another practical features.

If a user has several effective antiviral programs and utilizes it, the most reliable protection against viruses is in its prevention as:

- creating of regular backups (for example, once a week – complete, every day – partial copy); the presence of uninfected copies allows rewriting a "sick" file, the presence of infected but not damaged copies will allow to restore files after the virus removal;
- making backup copies of installation memory media before the installing of new software (if they are installed on the infected program the information system output memory media can get be infected during installation);
- e-mail files that are sent or received check-up on viruses;
- using write-protected memory media when copying files to own hard drive; this will prevent the virusing of memory media and subsequent infection of other information systems;
- verification the memory media before files from it loading;
- permanent usage of the resident part of antiviral program which monitors all suspicious action during operation of information system.

7.4. Estimation of software reliability according the results of adjusting and normal operation

In the processes of software debugging, normal and research operation, it becomes achievable to use statistical data about the detected and corrected errors in order to refine the system design reliability assessments. For this purpose were developed reliability models containing parameters, point estimations of which are obtained at the software commissioning and operation results processing. These models differ in their assumptions about the dependence of the intensity of errors emerging during the time of adjustment and operation. Some of those models contain specific requirements for the software modules internal structures.

Exponential model by Schumann.

This model is based on the following assumptions:

- the total number of commands in the program of machine language is invariable,
- at the beginning of tests, the number of errors is equal to some constant value, at length of corrections, the number of errors becomes smaller, and at course of program correcting new mistakes are not made,
- program failure rate is proportional to the number of remaining errors.

Regarding the structure of the program module there made the following assumptions:

- module contains only one cycle operator in which are resided operators for information input, assignment operators and operators of controls in advance conditional transfer,
- nested loops are absent, but there can be present k parallel paths, if we have the $k-1$ controls conditional transfer operator.

At these assumptions met, the probability of faultless operation is given by the formula:

$$R(t,\tau)=\exp(-C\varepsilon_r(\tau)t)=e^{-t/T},\ \varepsilon_r(\tau)=\frac{E_0}{I}-\varepsilon_B(\tau),\ T=\frac{1}{\tilde{N}\left(\frac{E_0}{I}-\varepsilon_B(\tau)\right)} \qquad (7.18)$$

where:

E_0 – number of errors at the beginning of adjustment,
I – the number of machine instructions in the module,
$\varepsilon_B(\tau)$, $\varepsilon_r(\tau)$ – number of corrected and left errors per one command,
T – mean time between failures,
t – time of adjustment,
C – coefficient of proportionality.

To assess the E_0 and C there are used the results of adjustments. Assume that among the total number of the system test programs runs the r is number of successful runs, while $n–r$ – the number of runs that were interrupted by errors. Then the total time of n runs, intensity of errors and operating time per an error can be found by:

$$H=\sum_{i=1}^{r}T_i+\sum_{i=1}^{n-r}t_i,\quad \lambda=\frac{n-r}{H},\quad T=\frac{1}{\lambda}=\frac{H}{n-r} \qquad (7.19)$$

Assuming that $H=\tau_1$ and $H=\tau_2$, we may find:

$$\hat{\lambda}_1=\frac{n_1-r_1}{H_1},\quad \hat{\lambda}_2=\frac{n_2-r_2}{H_2},\quad \hat{T}_1=\frac{1}{\hat{\lambda}_1},\quad \hat{T}_2=\frac{1}{\hat{\lambda}_2} \qquad (7.20)$$

where $\hat{T}_1$ and $\hat{T}_2$ – test time for one error. Substituting here (7.18) and solving the system of equations, we obtain parameters for the model estimations:

$$\hat{E}_0=\frac{I}{\gamma-1}(\gamma\varepsilon_B(\tau_1)-\varepsilon_B(\tau_2)),\quad \hat{C}=\frac{1}{\hat{T}_1\left(\frac{\hat{E}_0}{I}-\varepsilon_B(\tau_1)\right)},\quad \gamma=\frac{\hat{T}_1}{\hat{T}_2} \qquad (7.21)$$

To compute the estimations we need, according the results of the adjustment, to learn the parameters $\hat{T}_1$, $\hat{T}_2$, $\varepsilon_B(\tau_1)$ and $\varepsilon_B(\tau_2)$.

Some generalization of results (7.19–7.21) look as following. Let T_1 and T_2 are times of system operation that correspond the adjustment time τ_1 and τ_2; n_1 and n_2 – number of errors detected in the periods τ_1 and τ_2.

Then:

$$\frac{T_1}{n_1}=\frac{1}{C\left(\frac{E_0}{I}-\varepsilon_B(\tau_1)\right)},\quad \frac{T_2}{n_2}=\frac{1}{C\left(\frac{E_0}{I}-\varepsilon_B(\tau_2)\right)}.$$

Hence:

$$\hat{E}_0=\frac{I}{\gamma-1}(\gamma\varepsilon_B(\tau_1)-\gamma\varepsilon_B(\tau_2)),\quad \hat{C}=\frac{\frac{n_1}{T_1}}{\left(\frac{\hat{E}_0}{I}-\varepsilon_B(\tau_1)\right)},\quad \gamma=\frac{T_1}{n_1}\Big/\frac{T_2}{n_2} \tag{7.22}$$

If T_1 and T_2 – solely the total time of adjustment, then $\hat{T}_1=T_1/n_1$, $\hat{T}_2=T_2/n_2$, and formula (7.22) coincides with (7.21).

If during the adjustment course it is made k tests at intervals $(0,\tau_1)$, $(0,\tau_2)$, ... $(0,\tau_k)$, where $\tau_1<\tau_2<...<\tau_k$, then to determine the maximum likelihood estimation is used equation:

$$\hat{C}=\sum_{j=1}^{k}n_j\Big/\left(\frac{\hat{E}_0}{I}-\varepsilon_B(\tau_1)\right)H_j,\quad \hat{C}=\left\{\sum_{j=1}^{k}n_j\Big/\left(\frac{E_0}{I}-\varepsilon_B(\tau_1)\right)\right\}\sum_{j=1}^{k}H_j \tag{7.23}$$

where:

n_j – the number of runs of j-st test that ended with failures,
H_j – time which spent on the execution of successful and unsuccessful runs of the j-st test.

At $k=2$ the (7.23) reduces to the previous case and its solution gives the result (7.22).

Asymptotic values of the estimations variance (for large values n_j) are determined according the expressions

$$\mathbf{D}\hat{C}=1\Big/\left\{\sum_{j=1}^{k}n_j\Big/C^2-\left(\sum_{j=1}^{k}H_j\right)^2\Big/\sum_{j=1}^{k}\left(n_j\Big/\left(\frac{E_0}{I}-\varepsilon_B(\tau_1)\right)^2\right)\right\},$$

$$\mathbf{D}E_0=1\Big/\left\{\sum_{j=1}^{k}\left(n_j\Big/\left(\frac{E_0}{I}-\varepsilon_B(\tau_1)\right)^2\right)-C^2\left(\sum_{j=1}^{k}H_j\right)^2\Big/\sum_{j=1}^{k}n_j\right\},$$

where $C\cong\hat{C}$, $E_0\cong\hat{E}_0$.

The estimations correlation coefficient:

$$\rho(\hat{C},\hat{E}_0)\cong\left\{\sum_{j=1}^{k}n_j\Big/\left(\frac{E_0}{I}-\varepsilon_B(\tau_j)\right)\right\}\Big/\left\{\sum_{j=1}^{k}n_j\sum_{j=1}^{k}\left(n_j\Big/\left(\frac{E_0}{I}-\varepsilon_B(\tau)\right)^2\right)\right\}^{0.5}$$

Asymptotic value of variance and correlation coefficient are used in order to determine the confidence intervals of values E_0 and C based on the Gaussian distribution.

Quite a number of studies indicate that the most appropriate for Schumann model is an exponential model of number of errors changing, along the adjustment time length changing:

$$\varepsilon_B(\tau) = \frac{E_0}{I}\left(1 - e^{-\frac{\tau}{\tau_0}}\right),$$

where E_0 and τ_0 are determined empirically. Then:

$$R(t,\tau) = \exp\left(-CE_0 / Ie^{-I/I_0}t\right)$$

Mean time to failure increases exponentially with installation duration time increasing:

$$T = \frac{I}{CE_0 e^{-\frac{\tau}{\tau_0}}}.$$

Exponential model by Dzhelinsky–Morandi. This model is a particular case of Schumann model. According to this model, the errors emerging intensity is proportional to the number of residual errors:

$$\lambda(\Delta t_i) = \hat{K}_{JM}(E_0 - i + 1),$$

where:
$\hat{K}_{JM}$ – coefficient of proportionality,
Δt_i – interval between the i-st and (i–1)-st errors.

Reliability of failure proof operation then is:

$$R(t) = \exp(-\lambda(\Delta t)) = \exp(-\hat{K}_{JM}(E_0 - i + 1)), \quad t_{i-1} < t < t_i \qquad (7.24)$$

At $\hat{K}_{JM} = C / I$ and $\varepsilon_B(\tau) = (1-i)/I$ formula (7.24) coincides with (7.18). In order to obtain maximally likelihood estimation for the parameters E_0 and $\hat{K}_{JM}$ at sequential observation of k errors in the time moments t_1, t_2,..., t_k we need to solve the system of equations:

$$\sum_{i=1}^{k}\left(\hat{E}_0 - i + 1\right)^{-1} = k\Big/\left(\hat{E}_0 - i + 1\right), \quad \hat{K}_{JM} = \frac{k}{A}\Big/\left(E_0 - \theta \cdot k + 1\right) \qquad (7.25)$$

$$\theta = \frac{B}{A\hat{K}_{JM}}, \qquad A = \sum_{i=1}^{k} t_i, \qquad B = \sum_{i=1}^{k} it_i$$

Asymptotic estimations of variance and correlation coefficient (at large k) are determined using the formulas:

$$\mathbf{D}\hat{E}_0 \cong \frac{k}{kS_2 - A^2C^2}, \quad \mathbf{D}\hat{K}_{JM} \cong \frac{S_2 K_{JM}^2}{kS_2 - A^2 K_{JM}^2},$$

$$\rho(\hat{K}_{JM}, \hat{E}_0) \cong \frac{AK_{JM}}{\left(kS_2\right)^{0,5}}, \quad S_2 = \sum_{i=1}^{k}\left(E_0 - i + 1\right).$$

In order to obtain numerical values of these variables the E_0 and K_{JM} must be replaced throughout with their estimations.

Weybull's model. Model is given by a set of relations:

$$\lambda(t) = m\lambda^m t^{m-1}, \quad R(t) = e^{-(\lambda t)_m}, \quad t = \frac{1}{\lambda}\Gamma\left(1+\frac{1}{m}\right)$$

The advantage of this model is that it contains an additional, in comparison with the exponential model, parameter m. Selecting the values of two parameters: the m – shape parameter and λ – scale parameter, one can get more precise correspondence with the experimental data. The values m are selected from a range of $0 < m < 1$. Parameter estimations are obtained by using the method of moments. For the shape parameter m, the values are found from the solution of equation:

$$\Gamma\left(1+\frac{2}{m}\right)\Big/\Gamma^2\left(1+\frac{1}{m}\right) = \frac{s^2}{\bar{t}^2}, \quad \bar{t} = \frac{1}{k}\sum_{i=1}^{k} t_i, \quad s^2 = \frac{1}{k}\sum_{i=1}^{k}(t_i - \bar{t})^2$$

where $\Gamma(x)$ – gamma function.

For the scale parameter λ, its rating is determined according the formula

$$\hat{\lambda} = \Gamma\left(1+\frac{1}{\hat{m}}\right)\Big/\bar{t}.$$

Structural model by Nelson. For the reliability index is taken probability $R(n)$ of fail-safe executions of n program runs. For j-st run, the probabilities of failure are as following:

$$Q_j = \sum_{j=1}^{N} p_{ji} y_i,$$

where:

y_i – an indicator of failure at i-st set of data,

p_{ji} – the probability of i-st set at the j-st run.

Therefore:

$$R(n) = \prod_{j=1}^{n}(1-Q_j) = \exp\left(\sum_{j=1}^{n}\ln(1-Q_j)\right).$$

If the Δt_j – time of j-st run, the failure rate is then:

$$\lambda(t_j) = \frac{-\ln(1-Q_j)}{\Delta t_j}, \quad R(n) = \exp\left(\sum_{j=1}^{n}\lambda(t_j)\Delta t_j\right), \quad t_j = \sum_{i=1}^{j} t_i \tag{7.26}$$

Practical use of formula (7.26) is complicated as a result of a plurality of inputs and a large number of hardly estimated model parameters. In practice, software reliability is assessed according the results of test trials which cover relatively small region of initial data area.

For a simplified estimation is proposed formula:

$$R(N)=\frac{1}{N}\sum_{i=1}^{N}E_i(n_i)W_i,\quad \sum_{i=1}^{N}W_i=N,$$

where:

N – number of runs,

n_i – number of errors at i-st run,

E_i – indicator of absence of errors at i-st run.

To reduce the problem dimension, the multitudes of input sets are split into disjointed subsets G_j, to each of which corresponds a certain path L_j, $j = 1 \ldots n$. If L_j has errors, then at the test performance along the subset G_j will emerge a refusal. Subsequently the probability of correct performing of single test is

$$R(1)=1-\sum_{j=1}^{n}p_j\varepsilon_j,\quad p_j=\sum_{i\in G_j}p_{ij},\quad \varepsilon_j<1.$$

At this approach, to find an assessment of reliability using the structural model is difficult, since the error in L_j appears not at every set from the G_j, but only at some of them. In addition, there is no method for the ε_j estimation based on the results of programs testing.

It should be noted, that for this model, at present, has not yet been found a sufficiently reasoned justification for its implementation.

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8. Maintenance of information system

In the following section are presented materials on general maintenance of information systems. Naturally, each particular system has a specific and concrete content of its maintenance, which is formalized as the relevant technical documentation for the system maintenance. We briefly cover the basic methods of preventive operational control and maintenance of the functioning objects [1–9].

8.1. General issue

The nature of information system is such that the occurrence of failures in the system can be invisible for a long time while lead to a loss of efficiency. In order to reduce the information system failures flow during normal operation and increase an availability factor, it is to be planned and carried out the maintenance of an information system in which by different methods are detected unreliable components, modules, systems which have fulfilled their service lifetime till end. Such objects can be detected at an external examination or as a result of operation functions deterioration during circuit's modes and external modes testing. For this purpose, it can be, for example, changed the voltage supply, test signals frequency, created noise, and deteriorated temperature. Under these conditions, unreliable items can be identified by the presence or sudden failures or malfunctions. To ensure the continued integrity and performance of systems there are proposed the following recommendations:

- system technical maintenance, including preventive, should be carried out during the time intervals recommended according the guidelines,
- information system repair and maintenance must be conducted by authorized maintenance staff workers,
- all faults must be recorded in the relevant documentation, including the database of system functioning over time.

In the technical documentation for system maintenance must be defined the following.

Inspection – an event that is conducted by attendants or in automated way in order to observe the state of the system.

Automated surveillance is carried out as an internal or external with respect to the system resources.

Operation of maintenance and repair – a sequence of technological operations for maintenance and repair which are carried out with a certain purpose.

Maintenance – a set of measures to support the system operable state or the performance at using it for the targeted purposes, at storage and transportation.

Maintenance includes the regulated in constructional (project) and (or) service documentation for the operable and technically high-quality technical support continuation. Maintenance includes preventive maintenance, on which we will focus in detail.

8.2. Preventative Maintenance

Preventive maintenance of equipment is a set of measures aimed at the prophylaxis of failures for the lifetime extending. At the organization of maintenance works emerge controversial requirements. On the one hand, increasing the frequency and duration of maintenance working can increase the reliability indices in the period between successive sessions of prophylaxis. On the other hand, it increases the total downtime that may be economically inefficient. It is advisable therefore to specify two things: the content of maintenance working and time intervals defining for its performance. A variety of responses for these two problems solving will be discussed in the following subsections.

Classification of prophylaxis methods. At determining the preventive measures timing it should be selected the principles of time terms and the timing modes (strategy) assigned in order to conduct prophylaxis. There are three principles of such appointment terms: routine, calendar and combined.

In principle, *routine* prophylaxis is carried out at achieving a certain operating time. Operating hours can be measured in units of time, mileage, number of landings, number of switch in – switch out et al.

Routine principle is used for the systems that operate continuously without interruptions or for the heavy duty conditions case – in cyclic mode.

Calendar principle is used when the system is in standby or storage mode or in mode of a cyclic repeated use, i.e. when the intensity of wear is almost independent on operating time, but only from "age" of the system. In cases when the wear occurs both at work and during storage, it is used a combined principle of prophylaxis measures assignment. If the system is in operation, then the prophylaxis is carried out after reaching a certain time to failure. If the system is for a long time in storage mode, the prophylaxis is conducted in the forthcoming calendar dates.

Modes of prophylaxis can be of three types: *planned, unplanned and mixed.* At the planned prophylaxis mode it is carried out over a settled time, in accordance with the principles of time appointments, regardless of the number of failures that were occurred. This mode is often used in aeronautical engineering. Prophylaxis of *irregular* manner will be required by the technical state of devices, and particularly after the failures. In addition to such repair (rehabilitation) measures it is conducted some maintenance working. At the *mixed* mode are combined both planned and unplanned prophylaxis. The time term of regular routine prophylaxis is counted from the date of the preceding if between prophylaxes did not happen a failure, or from the end time of unplanned prophylaxis.

Preventive maintenance, carried out in a planned or mixed mode, can be arranged *cyclically* or *continuously.* Periodic maintenance is applied for the systems which cannot be afforded to stop for prophylaxis execution. After an operating time equals to be between routine inspections periods, the system is removed from use and directed to prophylaxis. Continuous service is used when the performance of preventive maintenance is possible without the system stopping.

Content of maintenance working depends on many factors, including the type and physical nature of failures, the system's diagnosis, the presence of structural redundancy, a fault diagnosed but not led to failure, availability of sufficient statistical data that allows establish a growth in failures intensity over time due to aging and wear of the system. In this regard, it can be distinguished four *different situations.*

1. At growth of incremental (parametric) refusals, the control determinant characteristics values and comparison of its current value with the critical values can confidently establish the need for the preventive working, either to regulate the determinant characteristics, or to make change in any item. However, according the value of determinant characteristic it is not always possible to determine precisely the cause of its deterioration. Sometimes it is required to conduct quite complex diagnostic procedures in order to determine which item causes the change in the values of determinant characteristic. For example, reducing the semiconductor amplifier gain can be of complex nature, for the detection and removal of those it will be required to carry out several maintenance works.

2. The following situation is when to the sudden emerging of failures precedes an occurrence of faults, a definite percentage of which can be identified with some confidence during the prophylaxis process. Troubleshooting of the problems found, and the making reasons for their occurrence analysis, prevent the emergence of possible failures.

3. The third method for prophylaxis conduction is a preventive replacement. In this case, the initial operating modes and faults of the object are unknown. After a certain operating time, as a result of aging and wear, the failure rate increases substantially. So there is conducted preventive replacement of still workable items, i.e. items replacement for the resource advance or taken the planned preventive maintenance measures.

4. The concluding situation occurs in structurally redundant systems, when with subsequent rejections of certain elements; the performance of the reservation system still subsists, but decreases the multiplicity of redundancy, which can significantly reduce the probability of failure-free operation in the future. Prophylaxis there consists in identifying the elements that failed, and the primary structure restoration. For example, at the circuit-element majoring according scheme "two of three" the system performance can be maintained even after rejection of the third part of elements. At unplanned prophylaxis, after a system rejection there is updated only redundant group items that failed, but at the planned preventive maintenance – all reserved groups. At mixed mode, updated are all groups, both at the planned and unplanned prophylaxis.

Types of maintenance. Preventive maintenance for most types of equipment can be carried out in three stages; at each of those are conducted specific types of working.

Step 1. Prophylaxis of switched-off equipment. At this stage is conducted visual examination of soldered joints and connections locations, cleaning the equipment items and assemblies, replacement of drying items and lubricants in the moving parts, checking installation insulation quality, cabling, checking diversion of charges in electrolytic capacitors, correcting the operation of contactors and relays control using appropriate informational – measuring devices.

Step 2. Tests of components and equipment under voltage. At this stage it is carried out the operational modes of equipment installation, regulation and adjustment of individual elements and devices, verifying performance of elements and blocks in normal and special modes, troubleshooting and preventive replacements of items.

Step 3. System preparing to work. At that stage is conducted equipment performance monitoring in the normal and special modes, integrated debugging and verification of major characteristics of the system characteristics, as of a whole. At each stage, the service operations are conducted in order to discover the faulty elements and to make its preventive replacement or renewal. At the first stage, such procedures may concern burnt resistors, worn sockets, cables, brushes of electric motors replacement, relay contacts cleaning, and others. At the second step it is made the search and replacement (recovery) of faulty items if it could not be defined from the initial operation modes and the nominal values of the characteristics changes tolerances or the responses limits of equipment elements and components with the help of the controlling utensils. At the third stage it can be made also troubleshooting. However, some working that has been carried out earlier, for example the system node configuration adjustment can be repeated.

Characteristics and optimization of preventive maintenance. As it was noted earlier that preventive measures may lead to some conflicting effects, on the one hand, they can improve the reliability of equipment operation. On the other hand, because of the time spending required to conduct preventive maintenance it reduces the effectiveness of the product use as it requires some definite profile specialist's worktime, test equipment, tools, spare parts etc. By certain choice of maintenance working characteristics it can be managed or balanced these effects. However, these characteristics are numerous: the timing of prophylaxis, the initial values of parameters and characteristics, depth of control, the desired number of staff attendants, the duration of prophylaxis, preventive maintenance costs, etc. A prophylaxis, which had provided an effective change of certain characteristic, may be unacceptable for another characteristic. The most well known is the prophylaxis time period (term) optimization tasks solution with the constraints onto other characteristics. As the criterion functions (optimization functions) it can be used the preventive effectiveness, as the ratio of object operating time mean value after prophylaxis and before prophylaxis; the coefficient of prophylaxis influence as the ratio of the average number of detected faults to the average number of all faults; one of the reliability characteristics (availability factor, the rate of operational availability etc.); economic indicators (average specific income, specific losses).

Training, refining and preoperational tests. Training (training trials) is intended to detect the production systems development flaws and defects. According the methods of flaws detecting in the construction and technology, it can be put into service also provoking tests. The complexity of these tests lays in its rational intensity choice: at very high actions intensity the failure occur for the reasons that do not occur at normal operation of lower intensity, not all reasons can be detected with this test.

If there present defects in manufacturing or caused by unscheduled degradation processes, the system training test allows to define or "to burn" weak elements and due to the effect of coupled period of adjustment (running-in) to diminish (sometimes very significantly – ten times order) failure rate during operation.

The effectiveness of failures prophylaxis increases a far as the initial signs of failures can be detected by the methods of nondestructive testing, suitable for use in the quality control and analysis of failures causes. Examples of such methods can be presented at the electronic equipment amplitude-frequency characteristics failures identification and also according the results of the thermodynamic hysteresis during thermal stress study. To the training trials of composite products can be added the tests that intensify (enforce) performance testing under adverse combination of external and internal factors.

To the researching (working out) tests belong all tests that are carried out in accordance with the design documents during working out of experimental prototype system. These tests according its final goal are divided into *autonomous* and *complex*. The objectives of the *autonomous* tests is to identify and eliminate the invalid and unreliable electric and radio equipment and component items and operation modes, determining of boundary (stock) performance, assessment of prototypes conformity to the designed specifications.

Comprehensive testing is carried out at the experimental working out of joint operation of several or all subsystems for compliance to specification. Distinguishing of tests onto independent and comprehensive can be conducted by a number of functionally independent operations conducted in a multifunctional system. If to work through the implementation of one only functionally independent operation, the test then is referred as autonomous. At the execution of working out of some several or all functionally independent operations, it refers as comprehensive testing. The final decision on the referring of testing of a particular type takes constructor's (project manager) solution, according with the program for development of an experimental prototype formation.

The objectives of integrated testing is to verify: the system components mutual functioning applied at autonomous tests; various factors imitating simultaneous influencing in the close to real conditions; eliminating of design and manufacturing defects at the interface between system and connected (adjacent) units, devices; testing of products when simulating extreme emergency and other situations that can affect the system control safety and which can be implemented technically on the test benches without violating the safety requirements for the experiment.

Preoperational tests belongs to the class of functional and are conducted before commissioning the system into operation, after each changing in the constructional documentation and composition of the system, after rehabilitation and maintenance routine. A facility operation is considered normal if the system conducts all required functionally independent operations, if the docking of all elements is done correctly, parameter values of interacting elements are consistent, and the information exchange between them occur without any violations that may result in failures in the equipment or in items within the succession of interacting devices.

In addition to qualitative assessment task, before launchers testing, there can be set the tasks of quantitative assessment of system efficiency characteristics (such as productivity, throughput) and also for system elements and all system characteristics affecting their values.

Identification and elimination of detected faults, operation modes adjustment, eliminating defects in the ways of interaction of subsystems and components help to prevent failures and improve the reliability of the examined system.

8.3. System repair and operation control

First we consider the terms used at the system repair operations:

- *repair* – a complex of operations used to restore the systems operable state or performance, resource of a system and its components recovery,
- *unplanned repairs* – maintenance and repair, which are made subsequent to the system failure detection in order to return it to state in which it can conduct the required functions,
- *active repair* – a part of unscheduled repair, which consists of operations that are conducted by the repair team,
- *completeness of repair* – the percentage of system faults that can be successfully eliminated.

Transfer from a system critical condition into working state is conducted by using repair during which the system resource recovers as a whole. The repair includes disassembling, defects discarding, replacement or restoration of individual units, parts, components units, assemblies etc. The content of some repair operations can match the content of the maintenance operations.

Recovery involves the identification of failures (finding out its location and nature), item which failed repair or replacement, technical state of the system operation adjustment and control; final control of system altogether performance.

Recovery – an outcome that after a system malfunction it again restores the ability to conduct the prescribed functions.

The following points are characteristics of faults:

- *identification of faults* – an event identifying the existence of faults,
- *failure detection, diagnosis* – operations that are conducted for positioning of the emerged failures, failures locations and its causes identification,
- *identification of the fault locations* – operation, that is conducted to identify the faulty component part or components at the corresponded object's smaller item division level,
- *completeness of troubleshooting* – the percentage of faults that can be detected at definite circumstances,
- *troubleshooting* – operations that are conducted after the failure location detection in order to restore the system ability to conduct the desired function.

Estimation of repairs time is carried out according the characteristics:

- *average time of active repair* – mathematical expectation of the of active repair duration,

- *average operational time of unplanned repairs* – operational time mathematical expectation for the unplanned repairs,
- *average duration of delay for organizational reasons* – mathematical expectation of time delay required for organizational reasons,
- *average duration of delays due to the insecurity of material resources supply* – the mathematical expectation of delays duration due to the insecurity of material resources supply.

Timing calculations for the completion of all operations that meet the technology of repair requirements include:

- *duration of programs treatment* inside the faulty information system. This duration is measured from the occurrence of failure until its detection. Faulty systems may destroy the results obtained,
- *duration of disability from the time* when an operator had recognized a fault till his/her addressing to the repair employee,
- *wait time till repair*, which depends on the repair service,
- *the duration of the fault* depends on the duration of diagnosing and troubleshooting and also from the number of controls and diagnostics means for disassembly operations, for failed system replacement, information systems assembling,
- *time duration of information system restarting* after repair, which includes the duration of software loading.

The nature of information systems is such, that failures that appear in it can be unnoticed for a long time but may cause considerable damage. In order to reduce the failures flow in the information system during normal operation and increase by this factor its readiness, there to be planned and carried out:

- maintenance (maintenance working), during which it is carried out cleaning, lubrication, external inspection and regulation of all the devices of information system (active maintenance),
- measures have to be taken to protect information systems from adverse surrounding factors (passive maintenance – maintenance of cleanliness and acceptable room temperature, eliminating vibration and other similar factors),
- identification of devices that have exhausted their resource (preventive prophylaxis).

Active maintenance is largely confined to the removal of dust, which affects the cooling of information system which contains current conductive tracts that can cause short circuits and substances that can accelerate oxidation and disruption of electrical contacts. At the precautionary maintenance services of devices which had exhausted their resources, the faults are detected during external examination, such as in the electromechanical devices of an information system, or found by the deterioration during testing of the inner and external modes of system operating. For this purpose, it is possible, as it was noted earlier, to change such parameters as voltage supply, clock signals frequency, to interfere, to impair temperature regime. Under these conditions, unreliable nodes can be identified either by the sudden failures emerging, or by the failures frequency growth. Forewarning maintenance is similar to the factory testing (training), so it is required to carry it out only after a thorough study of its feasibility [4,7–9].

Feasibility of *technical, including preventive, maintenance working* of an information system can be demonstrated as the following.

It is believed that the failure rate in information systems is constant and equals λ. Denote λ_1 and λ_2 as failure rate according with working and preventive time intervals. If we start from the hypothesis that the average failure rate of the maintenance does not change, then

$$\lambda = \frac{N}{T}, \quad \lambda_1 = \frac{N_1}{T_1}, \quad \lambda_2 = \frac{N_2}{T_2}, \quad N = N_1 + N_2, \quad T = T_1 + T_2 \tag{8.1}$$

where:

N – total number of failures during the T,
N_1 and N_2 – number of failures during working hours and during maintenance,
T_1 and T_2 – he total duration of time intervals in the duty cycle and the cycle of maintenance.

From there:

$$\lambda = \frac{N_1 + N_2}{T_1 + T_2} = \frac{\lambda_1 T_1 + \lambda_2 T_2}{T_1 + T_2} = \frac{\lambda_1 + \lambda_2 k_n}{1 + k_n} \tag{8.2}$$

where $k_n = \dfrac{T_2}{T_1}$ – coefficient of maintenance.

Solving the last equation with respect to λ, we obtain:

$$\lambda_1 = \lambda - k_n(\lambda_2 - \lambda) \tag{8.3}$$

From it follows that the maintenance is advisable only when $\lambda_2 > \lambda$. Thus there are two ways to decrease λ_1: by increasing either k_n or λ_2. As it was predicted earlier, the system failure rate λ is thus unchanged. However, for both as in the first and in the second cases there are limits. The raise of k_n means an increase in time share spent on maintenance. Since at that time the information system is not loaded with problems solving, it should be attributed to the loss of working time. Of course there are attempts to reduce losses, and they are constrained on the changing of k_n.

Regarding change in values λ_2 it should be noted the following.

Significantly weaken information system operation mode during maintenance for sure should not to be done, since otherwise it may lead to the refusal of the blocks still fit for further service. It restricts the changes of λ_2.

As it was noted earlier, the major tasks of maintenance comprise the following definitions: content of maintenance working; time-intervals (timing) for maintenance carrying out.

The first task setting is determined by its type, by performing the required sequence of n functions, by operation modes of the studied information system, i.e. for each particular system is formulated, as a specific mission, a statement, defining the content of maintenance procedures.

With respect to the second task statement we note the following.

It is known that the maintenance takes place at fixed intervals (once a day, week, month, quarter, year etc.). The time duration for maintenance depends on its frequency. If to cling to more frequent service, the duration must be less and vice versa.

Below we consider the following case.

Let during the system operating within the time interval between scheduled maintenances has happen a refusal, which in turn has led to an unscheduled maintenance.

Then the cycle time T_c to the next scheduled maintenance is defined as

$$T_C = T_P + T_{ef},$$

where:

T_p – continuous uptime of the system,

T_{ef} – maintenance time for elimination of failure.

Availability index thus equals

$$k = \frac{T_p}{T_p + T_{ef}}.$$

In general, the uptime T_P is a function of the time duration T_{ef}, i.e. $T_P = f(T_{ef})$. Then we have:

$$k = \frac{f(T_{ef})}{f(T_{ef}) + Tef} = \frac{1}{1 + \dfrac{T_{ef}}{f(T_{ef})}}.$$

Thus the coefficient of readiness k will grow up to 1, given that the component $T_{ef} / f(T_{ef})$. will be reducing to zero.

These expressions permit, basing on this examined system operation date, to find to a certain extent optimal time for unplanned maintenance T_{ef}. It should be noted that this definition of value T_{ef} is viable only with the known functional dependence $T_P = f(T_{ef})$.

From the physical considerations it is clear that the relationship between T_p and T_{ef} exists, but this dependence is more statistical, than functional. Therefore, the given expressions can be used to determine the approximate value T_{ef}, and further refinement of the approximated value is carried out together with the statistical data about failures in the examined system accumulation.

For highly redundant systems important is its maintenance, based on which, the components which were denied, are removed, including the components, which drop can deteriorate reliability dramatically. A proof for that is a system characterized by a multiplicity of reservations. For example, if in such a system with multiplicity three have had happen a refusal, the system reliability proportionally will grow to $R^2(t)$, where $R(t)$ – system reliability without reservation. To update system reliability is possible only by substitution of the item that had refused by a new one during maintenance.

Below we consider the cases of information systems maintenance.

In the information system, the errors, crashes and failures can occur as a result of improper actions of operator. Objects reliability function "operator system" can be estimated according the formula:

$$R = \prod_{i=1}^{n} (1 - p_i) \tag{8.9}$$

where:

p_i – the probability of errors at i-st stage of the information system,

n – the number of steps.

At the first approximation for the system operation such stages are five:

- preparation of information for the input into the information system,
- entering information into the information system,
- information processing in the computational system,
- transfer of information to the operator,
- perception and information processing by an operator.

Here presented a series of digital data obtained by the results of statistical processing of measurement data in information systems.

Each of these stages can be divided into a number of elementary operations. Probabilities of a bona fide performance of the subsequent operator are diverse. For example, the probability of correct information perception from the display is 0.950, from the keystrokes, at typing – 0.993, to input one digit at entering information into the information system – 0.980, assessment of information – 0.985 etc.

We may account that the *estimation time T_B of repair* during maintenance of information systems are assessed by accounting of all operations duration that correspond to a technology of repair. Regarding the information systems recovery time assessment we consider below the values of time intervals statistical estimations, obtained, as it was noted earlier, as the results of statistical analysis for the following operations:

1. Time t_1 for program treatment for a wrecked information system. This time is measured from the onset of failure till its detection. The actual loss of computing time can be much larger because the idling information system can eliminate the earlier obtained results. At the programmed control of an information system it is believed that $t_1 \cong 0.25$ hour.

2. Starting time t_2 of downtime – from the moment when the operator noticed the problem, to his request for the repairman.

3. Time t_3 for repair waiting. The values t_2 and t_3 depend on the organization of repair service. If there is repairman on duty then $t_2 + t_3 \approx 0$. For centralized repair this time period can amount up to several days looked for repairman arrival.

4. The investigation and repair t_4 time is characterized by the costs on download and working over test programs, on efforts to remove failure and for re-execution of test programs

in order to ensure that the repair is really done. The value t_4 depends on the number of controls and diagnostics means, on the complexity of parsing operations, replacement of components, which were denied and the information system reassembling.

5. Time t_5 for the commencing information system working after repair is spending for software downloading. This time is determined by the quality of external devices, and ranges from 1 to 30 minutes.

If there is repairman on duty, then total time $T_t = t_1 + t_2 + t_3 + t_4 + t_5$. makes from 1 to 10 hours, depending on the type of information system maintenance and other factors. The engagement of a repairman on duty is suitable, if the annual amount of restoration working, which equals to $N(1 - K_r)\,T_P$(h), where N – the number of information systems, K_r – the coefficient of availability, T_P = 1 year = 8760 hours, is close to the annual fund-time of a regular repairman. Otherwise, it is better to use, for example, the services of a local service center (T_t = 10 ... 100 hours) or else of the manufacturer (T_t = 10 ... 200 h).

The calculation of the recovery time components as of random variables at the accumulation of statistical data volume allows not only evaluating the average repair time, but also to make assumptions about its distribution function. If all components are approximately equal, we can assume that the T_t has the distribution close to the normal law. If all the components T_t are the values of different order, we can assume that the distribution T_t corresponds to an exponential law. In this case, $R(t) = e^{-\mu \cdot t}$,where $\mu = T_t^{-1}$. More precisely, $R(t)$ can be determined by the recovery process modeling on information system or basing on the accumulated statistics for the duration of the conducted works.

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9. Information systems reliability forcasting and ensuring

Below is presented the selected set of reliability performance prognosis problems, results of study of system reliability determinant characteristic dynamics reflected in the stochastic processes of failures formation. Also there formulated the functions of the system residual lifetime using monotonic and no monotonic diffusion distributions of its determinant characteristics. The program to ensure the system reliability is considered as the major form for the results of scientific and technical systems guaranteed quality tasks solving implementation. In addition are considered the basic requirements for safety during systems testing and operating, represented the advanced research directions regarding the information systems reliability [1–11].

9.1. Reliability characteristics prognosis problem formulation

Theoretical and practical tasks of reliability systems performance prognosis at all stages of lifetime cycle are major scientific and technological research areas of the reliability as of science. For such problems of prognostics solutions are used methods implemented at several natural and technical sciences prognosis tasks. It uses the data collected at functioning of technical systems of varying complexity, at all stages of their lifetime cycle, and primarily, experimental testing data and systems operating data.

For example, the reliability characteristics prognosis can be carried out at the design stage of the system basing on the accumulated data for the processing of similar type systems operation, using another's reliability research results.

Problem of prognosis is especially relevant and important for the systems that are manufactured in single or small number of batch, but perform responsible functions, such as in multifaceted technical systems of nuclear power plants.

For such systems it is impossible to obtain an assessment of performance reliability statistics for their failures, especially for those high reliability targeted systems with redundant structure.

At problem solving regarding prediction it must be considered: the aggregate effects of various factors; the objective function of research setting task, informational security,

including software and mathematical prediction. Results of the predictions tasks solution allow determining:
- to what class of random processes belongs the process that examined,
- dynamics of the process during the subsequent time interval,
- prediction the studied process probability no-exit out of the established acceptable limits.

Depending on the prognosis characteristics and the goal of predicted function there are used the following methods:
- analytical prediction of reliability,
- reliability prediction based on system functioning implementations recognition,
- reliability prediction based on the physical and chemical processes in the system study.

Within these methods are several ways of prognosis which can be classified as following:
- prediction for a given time interval,
- predicting the reliability characteristics while the object conducting one of the *n* functions required,
- prognosis of integrated safety characteristics which is a quantitative characteristic of system performance all *n* required functions.

To solve the problem of system reliability most frequently are used methods that solve the problem of prognosis for a given time within prognosis interval.

To justify the choice of a particular method it must be able to predict its quality quantitative assessment. Each prognosis method must possess an appropriate quality characteristic. Among the well-known for quality prediction characteristics are:
- accuracy of prediction, which is characterized by a corresponding degree of process coordination derived from the prognosis and from the actual process,
- reliability of prediction, which coincides with the concept of reliability estimation obtained as a result of prognosis,
- informativety of the prognosis, which indicates the measure of investigated system information increase as a result of prognosis,
- completeness of prediction, which determines the ratio of the characteristics that are monitored to the total characteristics that determine the system performance,
- efficiency of prediction is defined as the corresponding function within the space of reliability characteristics and is a generalized (integral) parameter or simply the quality parameter.

9.2. Reliability prognosis, based on the system operation determinant characteristic dynamics analysis

During operation a workable system enables a performance of *n* required functions, and the performance of each function is described by relevant characteristics as a function of time. During the general formulation of the system reliability prognosis problem it is required to predict the dynamics of changes for each of these characteristics. But in some cases, among the sequences of these n characteristics, it may be justified only one of its as principal, or determinant, which characterizes the system reliability foremostly. Based on this statement, hereafter, we consider the task of system reliability prognosis within the frame of determinant characteristics dynamics changes analysis [1, 10, 11].

In chapter 3 (subsection 3.7) for such integral characteristics is proposed to use the characteristic formation (accumulation) of failures in the examined system. Dynamics of such characteristics change will be considered in this section.

Mathematical model of this characteristic is a random process $A(\omega,t)$, $\omega \in \Omega$, $t \in T$, which implementation at a fixed $\omega = \omega_1$ will be marked as $A(t)$, $t \in T$.

Such process, for example, can be the Gaussian random process with independent increments.

System reliability prediction problem and its solution will be considered in this section under certain conditions and will have a methodical nature with attached illustrations about realizations of the studied stochastic process $A(\omega,t)$.

First we consider the relevant assumptions for the problem of the system reliability prognosis. It is believed that a reasonable functioning of the determinant characteristic $A(\omega,t)$ that describes the mode of system operation, establishes the value of this characteristic that leads to the failure (ultimate state). Thus, for the implementation of observation over the process $A(\omega,t)$, that is the function of time $A(t)$, it should be defined statistical estimations of average rate of change and the variation coefficient for its speed rate; this generally makes it possible to calculate (predict) the reliability characteristics for the system, without using the mode of failure (fracture) of the system.

Thus, for the system reliability predicting it must be specified the following information about the dynamics of change at the functioning of the system determinant characteristic as of a random process $A(\omega,t)$:

- model of degradation process (monotonic or non-monotonic character of implementation),
- threshold meaning of limited value changes for the determinant characteristics A_{max},
- initial value of the determinant characteristics A_0,
- average rate of the determinant parameter change within operation conditions a,
- variation coefficient (mean square root deviation) for the determinant characteristic ν change rate.

Basing on the specific implementations of such characteristics analysis, or basing on a general analysis of the physical processes of degradation caused by the change of the determinant characteristics (wear, corrosion etc.) it can be formulated the dominant degradation process and defined its type (monotonic *DM* non-monotonic *DN)*. This serves as a reason for the decision to accept for the distribution operating time to failure (ultimate state) mathematical model from the corresponding species of distribution (DM – or *DN*-distribution). These distribution laws were described in section 1.4.3 (formulas (1.11) and (1.12) respectively).

The following are examples of these reliability characteristics for a random process $A(\omega,t)$, that describes the relevant processes of degradation in the examined systems, with a prospect to use the obtained characteristics for the problems of its prediction solution.

Example 9.1. Below we consider a stochastic process with independent Gaussian stationary increments $A(\omega,t)$ and monotone implementations, charts of which are shown in Figure 9.1. In this process, the model $A(\omega,t)$ is described in the form:

$$A(\omega,t) = A_0 + \eta_m(\omega,t) \tag{9.1}$$

where $\eta(\omega t)$ – random process which has the following characteristics:

$a = \mathbf{M}\left\{\frac{d\eta_m(\omega,t)}{dt}\right\}$ – the average rate at the corresponding time interval t of the system uptime;

$a > 0;\ \frac{d\eta_m(\omega,t)}{dt} \geq 0,\ \nu = \sqrt{\mathbf{D}\left(\frac{d\eta_m(\omega,t)}{dt}\right)}\Big/ a$ – variation coefficient.

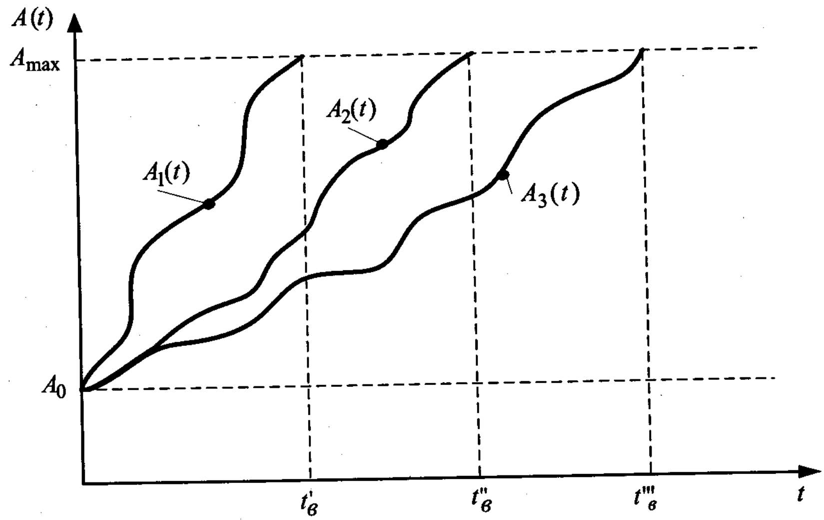

Fig. 9.1. Realizations charts of a random process with independent Gaussian stationary increments (monotone distribution)

For this case, the distribution function of operating time to failure (ultimate state) is:

$$F_{DM}(t) = \Phi\left(\frac{\alpha t + A_0 - A_{\max}}{\nu\sqrt{\alpha t\left(A_{\max} - A_0\right)}}\right) \tag{9.2}$$

Subsequently, the reliability characteristics of the system are as following:

– mean time between failures (average resource):

$$T_{cp} = \left(1+\frac{v^2}{2}\right)\frac{(A_{max}-A_0)}{\alpha} \quad (9.3)$$

– probability of flawless operation in the interval [0, t]:

$$R(t) = \Phi\left(\frac{A_{max}-A_0-\alpha t}{v\sqrt{\alpha t(A_{max}-A_0)}}\right) \quad (9.4)$$

Example 9.2. A stochastic process with independent Gaussian stationary increments and nonmonotonic distribution, implementations graphics of which are shown in Figure 9.2 is described in the form:

$$A(\omega,t) = A_0 + \eta_n(\omega,t)$$

where $\eta_{\mathcal{H}}(\omega,t)$ – the random process that has characteristics:

$\alpha = \mathbf{M}\left[\frac{d\eta_n(\omega,t)}{dt}\right]$ – average rate,

$\alpha > 0;\ \frac{d\eta_n(\omega,t)}{dt} \geq 0;\ v = \mathbf{V}\left[\frac{d\eta_n(\omega,t)}{dt}\right]$ – variation coefficient.

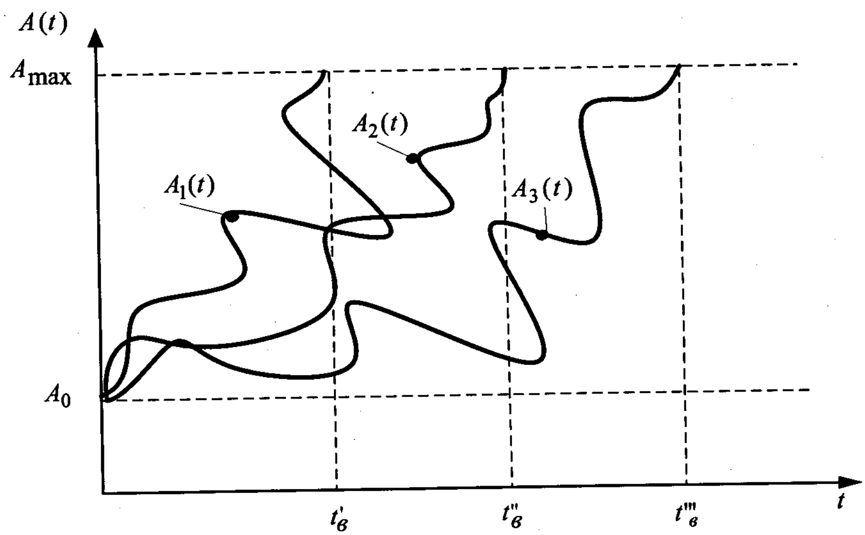

Fig. 9.2. Charts of realizations of a random process with independent Gaussian stationary increments (non-monotonic distribution)

In this case, the distribution function of operating time to failure (ultimate state) is:

$$F_{DM}(t)=\Phi\left(\frac{\alpha t+A_0-A_{\max}}{\nu\sqrt{\alpha t(A_{\max}-A_0)}}\right)+\exp\left(\frac{2}{\nu^2}\right)\Phi\left(-\frac{\alpha t+A_{\max}-A_0}{\nu\sqrt{\alpha t(A_{\max}-A_0)}}\right) \tag{9.5}$$

Expressions for the evaluation of object reliability indices are as following:

– mean time to failure (average lifetime):

$$T_{cp}=\frac{A_{\max}-A_0}{\alpha} \tag{9.6}$$

– probability of flawless operation in the range [0, t]:

$$R(t)=\Phi\left(\frac{A_{\max}-A_0-\alpha t}{\nu\sqrt{\alpha t(A_{\max}-A_0)}}\right)-\exp\left(\frac{2}{\nu^2}\right)\Phi\left(-\frac{\alpha t+A_{\max}-A_0}{\nu\sqrt{\alpha t(A_{\max}-A_0)}}\right) \tag{9.7}$$

These examples for characterization of reliability which can be used in prognosis problems are characteristic for a wide class of engineering systems, that include hardware, mechanical and electrical systems. For such complexes the processing of degradation (aging, wear and tear) is accumulated integrally, along the growth of time to failure t. Therefore, the most reasonable model for such physical processes is a stochastic process with independent increments. With regard to the large number of random factors in the degradation process, a typical model for increments distribution law with independent increments must be the Gauss law.

Determining such parameters values as the average rate of the process α change and the variation coefficient ν, as well as determining the initial value A_0 and limiting $A_{\max}$ for the studied systems operation can be made by calculation, using the known methods of mathematical statistics. It should be mentioned significant intricacy that could be met at such data statistical treatment problem solving.

9.3. System residual time to failure prediction

Technical systems operating experience has shown that the durability and service lifetime for many types of technical systems, including information systems, are, in some cases, reduced, because of reliability prediction errors at the stages of the system lifetime cycle, including the errors of the real operating conditions neglecting. This leads to premature termination of an appliance usage and, consequently, to an inefficient use of material resources spent on development, production and operation of such systems. In this regard, the practical importance lays in the assessment of the predicted (expected) remaining operating time (of resource, of service lifetime) described by the random process $A(\omega,t)$ i.e. by the operating time of the system after the moment τ (technical condition monitoring), if before that point the item did not fail (not reached the ultimate state). Knowledge of remaining operating time can effectively ensure a continued systems operation, planning time of items replacement and the prophylactics measures.

Naturally, the process $A(\omega,t)$ is applicable only for the systems that did not fail till (not attained the ultimate state) time τ. As it is known, the distribution of residual operating time of such systems may be obtained starting from the initial operating time distribution law (from resource).

The value of the residual lifetime $\tau_3(\omega)$ is a random variable, its major characteristic is the distribution function $F_3(t|\tau)$, which is a conditional probability distribution function and can be represented by the residual lifetime conditional distribution density $f_3(t|\tau)$ and conditional probability of flawless operation $R_3(t|\tau) = 1 - F_3(t|\tau)$, which is called the residual function of reliability. As the major indicators of residual lifetime resource we consider: average residual lifetime $\tau_3(\tau)$ which is defined as the mathematically expected value of the residual lifetime $\tau_3(\omega)$ after an operating time τ.

At determining the characteristics of the residual lifetime are considered, as the given, the initial reliability characteristics, and namely: probability of flawless operation $R(t)$ or, correspondingly, failure probability distribution function $F(t)$ or refusal probability density function $f(t)$.

Probabilities distribution density function of the residual lifetime $f_3(t|\tau)$, which is the conditional density obtained from the expression for initial resource distribution density of $f(t)$ and corresponding time shift to τ looks like

$$f_3(t|\tau) = C(t)f(t) \tag{9.8}$$

where $C(\tau) = \dfrac{1}{\int_\tau^\infty f(t)dt}$ – normalized multiplication factor.

Thus, the residual operating time conditional density in general case looks as following:

$$f_3(t|\tau) = \begin{cases} 0 & \text{at} \quad t<\tau \\ \dfrac{f(t)}{1-F(t|\tau)} & \text{at} \quad t\geq\tau \end{cases} \tag{9.9}$$

From last relationship the remaining operating time mean value (mathematical expectation of remaining operating time) is defined as following:

$$T_3(\tau) = \int_\tau^\infty (t-\tau) f_3(t|\tau) dt = \frac{\int_\tau^\infty (t-\tau) f_3(t) dt}{1-F(\tau)} = \frac{\int_\tau^\infty (t-\tau) f_3(t) dt}{R(\tau)}. \tag{9.10}$$

In Figure 9.3 are shown the graphs for the initial failure probability distribution density $f(t)$ functions and the residual lifetime probabilities conditional density $f_3(t|\tau)$.

For a comparative analysis of functions $R(t)$ and $R(t|\tau)$ which describe respectively the initial uptime distribution function and the conditional uptime distribution function – the residual functions of reliability, we shall use the following graphical illustration given in Figure 9.4.

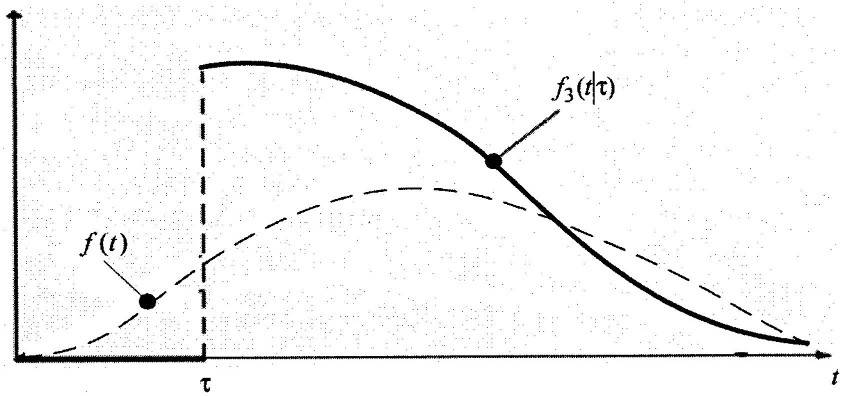

Fig. 9.3. Graphs of the initial operating time distribution density functions $f(t)$ and the residual lifetime distribution density $f_3(t|\tau)$ for the moment τ

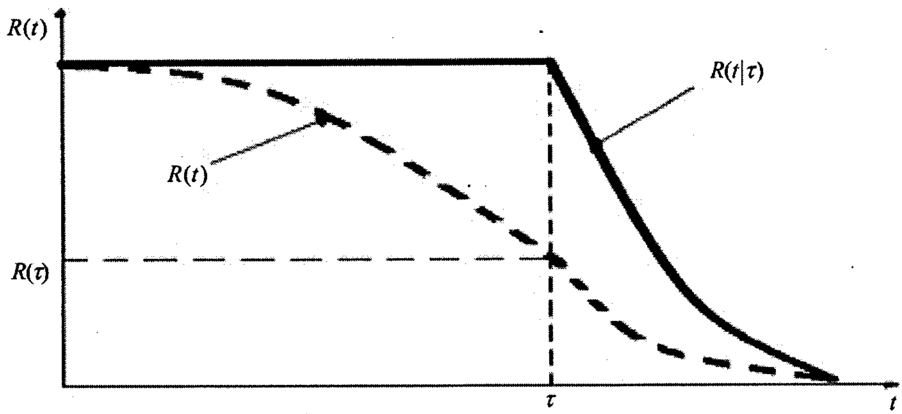

Fig. 9.4. Initial reliability functions $R(t)$ and residual reliability $R(t|\tau)$ graphs

In Figure 9.4 are shown the graphs of function $R(t)$ (dashed curve) and the residual reliability $R(t|\tau)$ function (unbroken line). Function $R(t|\tau)$ corresponds to the function $R(t)$ in the interval $[\tau; +\infty]$, at there, the start of the function $R(t|\tau)$ is transferred to the point τ, that is, as the beginning point of the new system is set τ (time condition monitoring), and the value of $R(t)$ in the new system is assumed to be one. Thus, for the function $R(t|\tau)$ in the interval $[\tau; +\infty]$ the scale of axis R is increased by the amount $\frac{1}{R(\tau)}$. In the new scale, the sector of function $R(t)$ at the interval $[\tau; +\infty]$ is the residual reliability function $R(t|\tau)$.

9.3.1. Determination of residual lifetime based on diffusion monotone distribution

In the state standards for the technical systems, where crucial are the failures of mechanical devices and units, it is recommended to use DM-distribution as a theoretical model of the operating time to failure distribution (ultimate state).

It is known, that in the modern methods for the varying complexity technical systems reliability research, to describe the processes of degradation (aging, wear, corrosion, cracking, generation and movement of electrical charges on the surface of semiconductor crystals and many more) are used mathematical models of continuous Markov processes of diffusion type.

It is accepted to describe physical processes of mechanical objects degradation by Markov proceedings with a monotone distribution (*DM*-distribution).

The density of *DM*-probability distribution, according to (1.11) (see section 1.4.7), is described by:

$$f_M(t) = f_M(t;\mu,\nu) = \frac{t+\mu}{2\nu t\sqrt{2\pi\mu t}} \exp\left[-\frac{(t-\mu)^2}{2\nu^2\mu t}\right] \tag{9.11}$$

where μ – scale distribution parameter, whose value is the inverse of the average rate of the degradation process $\mu = \frac{1}{a}$, ν – parameter form of distribution, the value of which is equal to the variation coefficient of degradation rate.

The function of *DM*-distribution:

$$F(t) = DM(t;\mu,\nu) = \Phi\left(\frac{t-\mu}{\nu\sqrt{\mu t}}\right) \tag{9.12}$$

where $\Phi(z) = \frac{1}{2\pi}\int\limits_{-\infty}^{z} e^{-\frac{x^2}{2}}dx$ – probability integral.

Probability of failure free operation:

$$R(t) = 1 - DM(t;\mu,\nu) = \Phi\left(\frac{\mu-t}{\nu\sqrt{\mu t}}\right) \tag{9.13}$$

The density distribution of the remaining operating time in case of *DM*-distribution:

$$f(t|\tau) = \frac{t+\mu}{2\nu t\sqrt{2\pi\mu t}\,\Phi\left(\frac{\mu-\tau}{\nu\sqrt{\mu e}}\right)} \exp\left[-\frac{(t-\mu)^2}{2\nu^2\mu t}\right] \text{ at } t \ge \tau \tag{9.14}$$

According to expression (9.10), i.e.

$$T_3(\tau)=\frac{1}{R(\tau)}\int_{\tau}^{\infty}(t-\tau)f(t)dt,$$

where $R(t)=\Phi\left(\frac{\mu-t}{\nu\sqrt{\mu t}}\right)$ – probability of flawless operation on the moment of time $t=\tau$, we get an expression for the average residual lifetime as for the corresponding mathematical expectation with the known probability distribution density function for the initial operating time $f(t)$ in the form of

$$T_3(\tau)=\frac{1}{\Phi\left(\frac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right)}\left\{\left[\mu+\left(\frac{1+\nu^2}{2}\right)-\tau\right]\Phi\left(\frac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right)+\right.$$
$$\left.+\frac{\mu\nu^2}{2}e^{\frac{2}{\nu^2}}\Phi\left(-\frac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right)+\frac{\nu\sqrt{\mu\nu}}{\sqrt{2\pi}}\exp\left(-\frac{(\tau-\mu)^2}{2\mu\tau}\right)\right\}. \tag{9.15}$$

Thus, the use of *DM*-distribution as of a theoretical model allows to predict the expected remaining operating time (resource, service lifetime) at any point in time, both at the design phase, where is used the same information as for the initial operating time (resource, service lifetime) predicting and also during operation stage, where it can be refined the initial assessments of reliability characteristics by using additional information regarding the system condition monitoring.

9.3.2. Determination of the residual lifetime based on diffused monotonic distribution

It is known that the *DN*-distribution is used in studies of technical systems reliability in which can emerge most significant failures of electronic components, modules, systems of units, in contrast to *DM*-distribution, where manifest failures of mechanical subsystems.

According to (1.12) the density of *DN*-distribution is described by:

$$f_n(t)=f_n(t;\mu,\nu)=\frac{\sqrt{\mu}}{\nu t\sqrt{2\pi t}}\exp\left[-\frac{(t-\mu)^2}{2\nu^2\mu t}\right] \tag{9.16}$$

where μ and ν – parameters of *DN*-distribution under similar parameters *DM*-distribution (9.11).

Probability distribution density functions of the residual lifetime $f_3(t|\tau)$, which is the conditional probability density, are obtained from the expression (9.16) in the form:

$$f_3(t|\tau) = \begin{cases} \dfrac{\dfrac{\mu}{\nu t\sqrt{2\pi t}}\exp\left(-\dfrac{(\tau-\mu)^2}{2\nu^2\mu t}\right)}{\Phi\left(\dfrac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right) - e^{\frac{2}{\nu^2}}\Phi\left(-\dfrac{\mu+\tau}{\nu\sqrt{\mu\tau}}\right)}, & t \geq \tau \\ 0, & t < \tau \end{cases} \qquad (9.17)$$

We can determine the expression for the mathematical expectation of the remaining resource $T_3(\tau)$ on the basis of formula (9.10):

$$T_3(\tau) = \frac{(\mu-\tau)\Phi\left(\dfrac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right) + (\mu+\tau)\exp\left(\dfrac{2}{\nu^2}\right)\Phi\left(-\dfrac{\mu+\tau}{\nu\sqrt{\mu\tau}}\right)}{\Phi\left(\dfrac{\mu-\tau}{\nu\sqrt{\mu\tau}}\right) - \exp\left(\dfrac{2}{\nu^2}\right)\Phi\left(-\dfrac{\mu+\tau}{\nu\sqrt{\mu\tau}}\right)}. \qquad (9.18)$$

The obtained on the basis of *DN*-distribution equations enable, with the use of system technical state reliability characteristics, during testing and operation measurement data to clarify the mean values of the remaining resource time duration at certain known calculated reliability characteristics, obtained during system designing.

It should also be noted that the combined use of *DM*- and *DN*-distributions in the research of reliability characteristics plays an important role in the information systems studies, in which are employed both mechanical and electronic subsystems. The relevance and importance of the technical system residual lifetime determining is largely due to the fact that there presents a considerable amount of technical systems in Ukraine which exceeded their service lifetime. This includes energy, transport, communal housing and other systems that occasionally cease to be operable, create accidents etc.

9.4. Methods of systems reliability scientific and technical problem solving

The system reliability scientific and engineering problem solving include strong organizational, scientific and technical activity directed to the implementation, planning, maintenance, enhancement and support reliability characteristics, maintainability, durability and preservation for the systems examined. Maintenance and reliability enhancement scientific and technical problem tasks can be solved basing on the methods of reliability analysis and synthesis.

Reliability scientific and technical problem analysis is a systematic study in order to determine the influence of design features on the system reliability, on manufacturing processes, usage, maintenance, and also on the determining the achieved reliability level as a result of planned measures finding in order to secure and increase the reliability and effectiveness of these taking measures assessment.

Problems of reliability analysis have to be solved to:

- verify the specified requirements accomplishment and (or) the quantitative measures (probabilities) assessments in order to achieve the components and the systems in general reliability requirements,
- *check the effectiveness of the implemented measures in design, technology, manufacturing*, processes of maintenance and repair finalizing, in order to increase reliability,
- reliability prediction and efficient ways selection to ensure or improve this characteristic.

Problems of reliability analysis have to be solved at the stages of specification development, conceptual and technical design, manufacturing and operation of structures at different levels of the system, i.e. at the levels of elements, parts, modules, subsystems and systems in general. Reliability analysis problems and its volume depends on the stages of the system lifetime cycle duration, the depth of testing for reliability, on consequences of failures, on ultimate state of the system and other factors. It is also important to use the results of analysis and information reliability problems solving during the design, manufacture and operation according the program of reliability ensuring.

9.4.1. Principal methods of system reliability analysis

At establishing the choice of method for reliability analysis it should be considered:

- systems reliability research problem class,
- adequacy and completeness of the mathematical model of the reliability characteristics, models performance, the model use initial requirements and limitations,
- the method usability for the computer simulation, for the data measurement during testing of the operation reliability characteristics statistical analysis in order to attain the calculation results accuracy characteristics,
- relevant to reliability characteristics formalization, employing information security methods, including mathematical and software research.

The sequence of the system reliability methods analysis is as following:

- system identification (purpose, scope, functions, structure, composition, backup, system maintenance, operation mode, external interaction, qualifications of staff and quality of the software tools used in technology system which are planned at production organization, during system manufacturing);
- purpose of the system appointed definitions (range and required reliability characteristics values, system operation quality criteria, consequences of rejections, failures and boundary conditions criteria),
- baseline data determination (obtaining and pre-processing of source data about the reliability of components and counterparts, calculating the elements reliability characteristics, reliability distribution by elements of the system),
- analysis of the system,
- qualitative analysis (identification of types of faults, failures of mechanisms and their implications for the system, analysis of the scheme functioning, analysis of maintenance and repair formats, building reliability system structural scheme),

- quantitative analysis (mathematical model construction for the considered system reliability characteristics consistency in order to obtain quantitative reliability characteristics by calculation or simulation, analysis of failures and sensitivity importance, assessment the feasibility of improving the performance of subsystems based on backup strategies and maintenance strategy),
- evaluation of analysis results (comparison with the desired reliability characteristics and/or guidelines and tools to ensure the required reliability characteristics, which may include design review, identification of weaknesses, imbalances of modes, parts with high-risk of malfunctioning replacement, development of alternative ways to enhance reliability, implementation of trade-off analysis and designs options evaluation).

Below we consider the program for reliability ensuring as the major form of scientific and technical reliability problem-solving results implementation.

9.4.2. Program to ensure system reliability

Such program is designed to ensure the reliability during the entire system lifetime cycle, beginning from the formulating the goal of a particular system until its complete exclusion from the use and disposal. It is known that the system lifetime cycle consists of the following steps:

- the goal rationalizing for the development and formation of construction strategy, working-out and coordination between the customer and the specification developer, drawing an appropriate (national, departmental or else) order for the system development,
- construction, technical design documentation development, system component prototypes manufacturing, its trials, adjustment of technical and design documentation for the model of the system serial production,
- preproduction, production of system components, assembling, installation, testing, certification and system transfer into operation,
- installation, commissioning, operation, maintenance and repair of the system;
- at the final stage of the lifetime cycle are conducted all the system studies results summarizing, including the reliability characteristics at the performance by the system those *n* indispensable functions; scientific and technical materials formal reporting as databases, system testing and operation services measurement results; establishment of appropriate information security, including mathematical; programming for the development a new, more robust perspective system. Also at this stage is conducted the system disposal, taking into account environmental requirements or taking solution on system future use for other purposes.

Given the significant amount of diverse working on the performance at the creating a system in order to ensure its safety, the program should include the set of interrelated with the essential organizational and technical requirements recommendations and actions to be conducted to guarantee and enhance the system reliability. The program can be created as a single document, but more suitable is to develop this program by stages:

- design and development,
- manufacturing and testing,
- operation.

Program to ensure reliability is the major document that makes it possible to accomplish a comprehensive approach to problems of software reliability with all the parties (developers, customers, consumers) solving, at all stages of lifetime cycle. Equipment reliability assurance program should be sent to the authorities for analysis, verification, control and maintaining the level of safety prescribed in the regulatory and technical documents. The content of the program to ensure the reliability depends on the design decisions, stipulated that there are specific restrictions and requirements regarding each system reliability importance. The program also should include practical recommendations to improve reliability during the process of recovery, repair and maintenance, depending on the operating data of the system.

Below we consider the program to ensure the reliability at the major stages of the system lifetime cycle.

At the stage of the *system basic characteristics rationalization* developing are to be formed, as the basic requirements, the structure, specifications, time limits and costs of development. At this stage are developed foundations of system reliability and the costs of its lifetime cycle. The means to ensure the reliability is required to justify according the basis of modern information technology. Typically, at this stage of development there is no precise information about the reliability of the system major parts and the starting point for the reliability assessing and production requirements is information about the analogues prototype systems and its components. As a method for accelerating the reliability evaluation at making choice for development strategy are recommended methods of simulation, statistical modeling and approximate priori calculation.

At the stage *of designing and developing of the system* is created a specific system technical implementation (hardware, software etc.), are developed technical documentation, instructions for use and maintenance etc. Means to ensure reliability at this stage are focused on meeting the requirements for reliability. The major objective of reliability ensuring is as following:

- designing process management in order to implement all requirements for reliability,
- defined and executed evaluation procedures to comply with the requirements for safety,
- development and implementation of tools for system reliability management,
- analysis, in terms of guaranteeing, the system reliability as of a whole aggregate of components and parts,
- tools for planning and providing maintenance are to be reconciled with the project system design to ensure appropriate requirements for reliability.

At this stage, the special role plays the problem of reliability, durability and maintainability of the system. As for the methods for rapid assessment of reliability at the design and developing stage are recommended methods and the refined priory approximate calculation techniques of accelerated comparative tests of prototypes, methods of accelerated forced tests, analytical methods for prognosis, methods of statistical analysis based on recognition of images, grounded on the study of physical and chemical prognosis processes and methods of simulation (computer) modeling. Using the sequence of methods will provide the most objective assessment of the system reliability and also will allow to check the results obtained by different methods.

At the stage of *manufacture, operation and spreading system* is produced, assembled, improved, tested, get certified and put into production. Means to ensure operation safety are concentrated on testing for reliability. During the tests are defined reliability characteristics, durability, maintainability and safety. The test strategy should provide an assessment of reliability risk of the producers and customers (users). As for method for rapid reliability assessment on the stage of production and installation is recommended method of accelerated forced tests (defining, identification and control) as well as the methods of prognosis.

At the stage of *operation, maintenance and repair* the system is used for its intended purpose, maintained and repaired. Means to ensure the reliability should be focused on operational information collecting, evaluation and analysis of faults and failures, on the strategy of maintenance and repair and spare parts provision. As a method for rapid assessment of reliability during operation is recommended cash-experimental method that represents a synthesis of a priori calculations and accelerated testing.

All over operation phase it is essential to complete all program's recommendations to improve system reliability by using adaptive techniques of real reliability characteristics measured data statistical processing results during the processes of recovery, repair and maintenance.

At the *final stage of the lifetime cycle* it is required to summarize all the results of scientific and technical systems reliability problem solutions, including the results on the program to ensure the reliability and create information support for the development of highly advanced systems.

Reliability analysis of programs ensuring the completeness and reliability of execution states for all the program activities results can confirm that the design and manufacturing process, technology and the system operating will meet the requirements that ensure specified requirements for reliability.

9.4.3. Requirements for safety during testing and operation

According to the law of Ukraine "On Labour Protection" at working place in every structural unit of an organization must be ensured labor safety conditions during systems testing and operation for reliability.

Such instruction is the normative act, providing the mandatory compliance requirements for a worker safety during systems testing and operating.

Provisions of instructions have to coach briefly, clearly, in accordance with the process sequence and subjected to the conditions in which are conducted the system testing and operation.

Instructions must include the following sections:

- general provisions,
- safety requirements prior to testing and operation,
- safety requirements during testing and operation,
- safety requirements after testing and operation,
- safety requirements in emergency situations.

If necessary, to the instructions should be added another subdivisions.

The following is the basic contents of the said sections for safety instructions at testing and operation.

General terms include the following items:

- the requirements and procedures for employees admission to work independently during testing and operation (requirements regarding the age, maturity, gender, health status, medical checkup, vocational education, special education, instruction, knowledge test etc.),
- major dangerous factors description at production, testing and operation, their influence on the employee.

Safety requirements before the operation and tests are as following:

- the rules for working shift acceptance at continuous operation, including the cases of testing and operation regimes violations,
- the order of running equipment and tools checking, safety devices, overview s machinery danger zones, the launchers, the fuses, brakes, locking systems and alarms, ventilation and lighting, availability of safety signs checking, the primary means of fire suppression, recognition of protective electrical earthling visible damages etc.

Safety requirements during testing and operation are as following:

- information about safety working organization, techniques and methods of safety operation, equipment processing rules, devices and instruments safe use as well as warnings about possible dangerous and incorrect methods and techniques of working, which is forbidden to employ,
- circumstances at which the testings have be terminated (technical, weather, health etc.),
- requirements for fire and explosion safety.

Safety requirements after testing and operation are as following:

- at the periodic cycles of testing and operation the order of safe shutdown procedure, termination, disassembling, cleaning and lubrication of facilities, equipment, vehicles, machinery and equipment,
- at a continuous process of testing and operation – procedure for the routine working shift transfer.

Safety requirements in emergency situations are as following:

- information on possible emergency situations features, typical causes of accidents (explosions, fires etc.),
- procedure, personal obligations and rules of an employee conduct in the event of accident according to the plan of localization and liquidation of emergencies and accidents, including if it occur during the transfer and acceptance of working shift at continuous testing and operation,
- information about use of fire protection and alarm systems,
- procedure for providing first aid to the hurt in an accident.

Manual for labor protection is an essential obligatory normative document, which is the part of the technical and design documentation during systems testing and operation.

9.5. Information systems reliability future research directions

Prospects for the development of informational systems should be considered primarily in terms of hardware and software systems reliability.

The historical roots of the basics of reliability can be attributed to the beginning of human civilization at the first technical resources appearing. In modern language, these foundations began to form around the 30-th of the twentieth century.

The rapid development of technical systems reliability theory in general, and especially scientific and technological progress in improving the information systems reliability for the past 20 years have indicated that the modern information systems can operate flawlessly for years. This situation sometimes creates pseudo revolutionary populist's statement that the reliability doctrines are exhausted and became unnecessary for the experts. However, the theory and practice of reliability resembles the medicine practice. The only difference in it is application, rather to a technology system, then for a human body. Can one imagine that medicine had run its course? In front of reliability science stand many important issues waiting to be resolved. We shall briefly consider some of them. We may conduct an analysis and evaluation of the effectiveness of systems, the element failures in which lead only to a partial degradation of the system. Effectiveness analysis of such systems can be reduced to the evaluation of their reliability by the selecting corresponding criteria of failures (e.g., denial – an event when the capabilities of the system are below a specified level). But this approach does not take into account the capabilities of the system to operate after a failure of some of its functions, but with lower efficiency. This may be, in some cases, very positive practice that should not be ignored.

There must be conducted an analysis and evaluation of survivability, as the ability to withstand external influences (predictable operator rough error, natural action – earthquakes, floods, hostilities, acts of terrorism, acts of war, etc.). Usually survivability analysis reduces to the analysis of "weaknesses" of the system and estimation of number of elements, destruction of which leads to stopping. This is an important criterion, but it ignores many factors (quick replacement of elements that were denied, "complexity" or "labor" of simultaneous large number of items refusal etc.) and the system properties.

There defined conditions of a system safety property, to function without dangerous consequences for humans and to the environment. For the analysis of the system survivability and safety it can become useful the probabilistic risks theory methods.

There must be conducted an analysis of systems security that must work not only safely, but also to be protected from unauthorized access, since it may deal with classified information. Since the operation of such systems cannot be considered normal if its protection does not work, it raises the question of "double reliabilities" – technical and informational.

In the modern situation important is a reliable software usage seeing that the functioning of the growing number of various systems which depends on the correctness and quality of software. At the attempts of research, in some cases the use of traditional concepts of reliability theory has proved to be ineffective. Reliability of software is largely determined with the experience and skills level of programmers, developers, results of software testing can classify the objects into "make-younger" systems.

The software is an implementation of the appropriate informational provisions, especially mathematical. Therefore, the overall reliability level setting is defined by the triad "model-algorithm-program" and by using the results of its research at applying modern methods of natural and technical sciences. Up to now, the reliability of hardware and software of systems is considered as the summing up reliability of two independent components – hardware and software. So, the promising scientific and technical reliability problems solution direction is the research on the relationship of hardware and software, in order to improve the reliability of hardware and software of information systems using modern informational technology of adaptation, of continuous monitoring, etc.

The human factor in the technical systems reliability is important because a significant portion of failures in human-machine systems are associated with the errors of attendants. Development of methodology for calculating and optimizing the reliability of the components of human-machine premises, taking into account the human factor would significantly reduce the costs loss for such systems operation.

Reliability analysis of unique items (for space stations, nuclear reactors, large hydraulic structures etc.) that usually are produced in single copies is important, because they conduct very responsible duties and therefore must be extremely reliable. Typically, these systems do not have a prototype; there is no experience to its setting up and usage. It is a question how to evaluate their safety and ensure reliability estimation.

Reliability analysis of global territorial systems (electricity networks, gas and oil pipelines, military systems etc.) for which even the term reliability defining is a very intricate task, still anticipates a creation of a special apparatus for its calculation and estimation.

Reliability analysis of telecommunication networks usually is confined to the reliability analysis of its service. However, the networks often have channels with diverse bandwidth; a significant amount of its quality and technical characteristics depends on the transmission of information and on the intensity of a requests. Taking into account the actions of all of these factors it requires interconnection of reliability theory and queuing theory and also some new research methods creation.

Statistical modeling is a versatile and efficient reliability analysis tool for complex systems, the mastering of which requires a high level of professionalism. Creating an appropriate information management, including mathematical and software, which adequately reflects the complex hardware and software systems functioning enables more deeply and effectively solve complex scientific and technical problems of reliability of such systems during their design.

Reliability analysis of systems that are at development requires a number of problems solving. A question is how to use current information about the system reliability to manage the process of its development? How to consider the future changes in the current design, the systems upgrading?

The problem of hierarchical systems of spare parts supply establishing for mass production through national, regional and local warehouses with the relevant rules of the location of warehouses and delivery of spare parts to the users still is waiting for its solution, possibly via the correlation of reliability theories and inventory management.

Accelerated testing in many cases is the only way to predict the reliability of new goods of mass production. Evidently, there is a problem of feedback of such tests based on the results of nominal operation. Only after this problem solving it can proceed to the development of the adequate models of reliability prediction on the basis of accelerated tests.

These tests and actual operation is a mandatory basis for reliability steadfast results. However, these data are found scattered, collected in different surroundings, obtained under dissimilar test plans or, even for some of them, samples are not completely identified. The question is how to combine properly such data in order to obtain reliable results.

We may consider the program implementation to ensure the information systems reliability.

Hardware and software subsystem for reliability maintenance insuring. Such subsystem is a component of the hardware-software complex. It is known that for the information systems is designed and implemented a program to ensure safety for all phases of its lifetime cycle. Expanding the number of safety characteristics, which include, along with the classical metrological functional characteristics, the extensive use of computer technologies in the hardware of the system, the introduction of modern information technology in both hardware and software components of the system allows to create advanced hardware and software subsystems to ensure reliability.

Summarizing this work, it should be noted that at present the relevance and importance of scientific and technical issues of information systems reliability is not being declined, and in a sense they are being grown. As it was noted earlier, this fact is due to the following:

- significantly increased the information systems complexity,
- enlarged demands for the economic and environmental safety conditions regarding the information systems operation and maintenance,
- reduction of terrestrial reserves of energy have prompted a solution of energy saving technologies in energy, transport, in the nuclear power and renewable energy sources branches development, that ultimately had lead to the creation of highly reliable information systems.

Thus, the above mentioned data make it promising to think about the fundamentals of engineering systems reliability, including information systems, as about a scrupulous science that meets all this challenging demands.

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Glossary

Access to information in the system – allows users to process the information in the system. The procedure for access to information is approved by the State, to the classified information, protection of which is set by the law – by the list of users and their credentials in respect to the information which is defined by the law.

Availability of information – possibility to use information when arises a need in it. The availability of information also characterizes the performance of a system.

Calculation method for reliability determining – a method based on the calculation of reliability characteristics according to the reference of reliability of components and component elements of the object and in conformity with the reliability analogous objects, in appliance with properties of materials and other information available at the time of calculation.

Calculation-experimental method for reliability determining – a method where the reliability characteristics of all or some parts of an object are determined from the test and (or) operation results, and reliability characteristics of the object as a whole are calculated by a mathematical model.

Classified information – information, access to which is restricted by the law or by the decision of the owner of such information or by authorized representative.

Coefficient of technical use – the ratio of the mathematical expectation of the total time spent at the facility working condition for a certain period of operation against to the mathematical expectation time of the total facility residence period in working condition and downtime due to maintenance and repair for the same period.

Comprehensive system of information protection – an interconnected suite of organizational and technical measures, means and methods of informational security.

Confidential information- information, which is in possession, usage or disposal of specific individuals or legal entities and is distributed at their discretion, in accordance with the conditions established by these.

Consequences of failures – events, processes, proceedings and conditions caused by the occurrence of object failures.

Criterion of failure – a sign or set of signs of abnormal function of an object set forth in the regulatory and (or) constructional (project) documentation.

Criterion of ultimate state – trait or set of attributes of the object boundary condition, established by regulatory and (or) constructional (project) documentation.

Depending on the operating conditions for the same object it can be set out two or more criteria for ultimate state conditions.

Defect – every single discrepancy to the set requirements.

Design techniques to ensure reliability – methods of reliability, which are used at the design phase of the object.

Duration of disability – the time interval during which the subject is in non-working condition.

Duration of the fault – the time interval that is a part of the operational lifetime spent on unplanned repairs, during which the fault is removed.

Experimental method for reliability determining – the method based on a statistical processing of data obtained in testing or during operation of an object.

Failure – an event that is subjected to the loss of ability to perform the desired function in violation of the working state of the object. "Failure" is an event different from "malfunction", which is a circumstance and the cause of failure.

Failure modes – forms of failure emergence. The types of failures are for example, circuit breakage or short circuit, an amplifier gain change etc..

Faultlessness – a property of an object to perform the required functions within certain surrounding in a specified interval of time or within time to failure.

Faults duration diagnosing – the time interval during which it is carried out the diagnosing of the problem.

Information (see all information) means "explanation", "presentation", "communication." The term became widespread in the late nineteenth century, but was originally used only for communications. With the development of science and technology the information began to be considered depending on its specific content and with the partition of species related to different fields of human activity.

Information about the object exists in a form of data. These are a set of specific values of quantitative and qualitative parameters characterizing the object. The object may include hardware, technical personnel, or any combination thereof.

At present, information is one of the most important and valuable products of human activity. For its existence information always requires a carrier of information, it is one of the resources that can be accumulated, implemented, up to dated, is suitable for collective use, and (unlike to other resources) does not lose its properties in the process of consuming.

The idiom "information" can be interpreted as how a certain set of data (messages) determine the scope of our knowledge about these or other events, actions, factors and their relationships.

Information features:

1) information about any event, someone's activities etc.; a notice about something;
2) collection of informational data which is obtained from the surroundings (the input information) or issued into the surroundings (the output information) or stored within a new system (inner information);
3) major element of any management functions, it must reflect the real world, processes and phenomena, to use a user friendly language, to be timely, useful and required by a user;

4) information is the knowledge, the data obtained and accumulated with the development of scientific and practical activity, which can be used in social production and management as the factor for production increase and its efficiency improved;
5) with respect to the electronic document, they are a set of facts, actions, and events of interest to be registered and processed.

In the above terms always exist: the information source and consumer of information. Both the first and second can be objects of science, technology, society, and nature, animals, people. In the interaction between them emerges information. Depending on the area of expertise are distinguished scientific, technical, commercial and other types of information. Information has become a commodity. There are several forms of information. Symbolic is based on the use of characters – letters, numbers, symbols, including punctuation and other characters. Information science direction that studies the laws, methods and techniques for collecting, processing and communication of information and is called informatics.

Information about an object can be seen as an imprint of this object in some materialistic system which can exist regardless of whether this information used or not.

Information is a special form of existence of matter. Like matter and energy, information may be collected, processed, stored, and changing its appearance form. However, it has some special features that lie ahead of all, namely that it can arise and disappear.

Information is one of the renewable resources. The process of its recovery consists of the stages of production, distribution and usage. Production (generation) of information is on fact in learning the status and the laws of nature and society process.

Information and telecommunication systems – an aggregate of information and telecommunication systems in the information processing which act as a single object.

Information network – a network designed to process, to store up and to transfer the data.

Information processes – the processes of information collecting, processing, accumulation, storage, updating and disseminating.

Information processing in the system – when one or more transactions including: collection, administration, recording, converting, reading out, deletion, checking, reception, processing or transmission are implemented in the system using hardware and software.

Inoperability (disability) – the state of the object on which it is unable to perform at least one of the required functions.

Integrity of information:

1) the ability of the computer technology or information system to support information invariance at the situation of accidental or deliberate distortion (destruction),
2) capability of information to find practical use in various fields of humane purposeful activity.

Integrity of the system – the property which consists in the fact that none of system components can be removed modified or supplemented in violation of security policy.

Lightweight reserve – reserve, consisting of one or more reserve items which operate with less, compared with the major element, loading.

Loaded reserve – a reserve that contains one or more reserve items that are in standby with the major element.

Maintenance period – the time interval that is a part of the maintenance and repair time period, during which it is carried out the object maintenance, taking into account the delay due to technical reasons and duration of delays due to the insecurity of material resources supply inherent to technical maintenance.

Normalized reliability response (index) – reliability index, the value of which is regulated by normative and (or) constructional (project) documentation for the object. As normalized reliability indices can be used one or more of these indicators, which are listed in the regulations (standard), depending on the purpose of the object, its degree of compliance with operating conditions, effects of possible failures, costs spending limitations, and the ratio of these facility reliability costs and the costs for its maintenance and repair.

Not repaired object (non repairable object) – an object whose repair is impossible or is unforeseen by regulatory, repair and (or) constructional (project) documentation.

Operational factor – probability that, in others than those scheduled periods during which the object is not used for its purpose, it, at any moment of time will be in working condition and will perform the desired functions over a given time interval.

Preservation – the property of an object to keep its characteristic within a given set of meanings, reflecting ability of the object to perform the necessary functions during and after storage and (or) transport.

Qualification testing – testing conducted by the developer and approved by a customer (in an opposite way) to demonstrate that the software meets the specifications for it and is ready for use in its intended surroundings.

Qualification – The process which demonstrate the ability of an object to perform the specified requirements.

Qualifications – set of criteria or requirements that must be satisfied in order that the software could be classified as being under the specifications and to be allowed to use in its target surrounding.

Quality assurance – all activities that are planned and carried out regularly as a part of the quality management system and are implemented properly to provide reasonable assurance that the facility will meet the quality requirements.

Reliability assurance program – a document that sets forth a number of interrelated organizational and technical requirements and measures that have to be hold at certain stages of the lifetime cycle of an object and to ensure the specified requirements for safety and (or) to improve reliability.

Renewable object – repairable item, which after failure and fixing the problem becomes able to perform the required functions with the given quantitative reliability characteristics.

Repairable item (repairable object) – an object whose repair is possible and specified by regulatory, repair and (or) constructional (project) documentation.

Resources, technical resources – the average time period between the object start from its operation begin or after renovation until advancement into the boundary state.

Safety:

1) an object property to ensure no risk of damage to human health, property or the environment,

2) protection of information and data in such a way that unauthorized person or organization could not read or modify it and at the same time it would not impede access to it by an authorized person or organization.

Saving efficiency ratio – performance indicator for the object in a form of ratio of the intended for a certain object operation time period values, to this parameter normal values, calculated assuming that the failure of an object during the same period will not occur.

Technical protection of information – the kind of information security, aimed at providing help for engineering activities and/or software and hardware to prevent leakage, destruction, blocking or violation of integrity and access to information.

Technological methods of reliability ensuring – methods of software reliability providing, which are used at the stage of a facility mass production.

Telecommunication system – a set of hardware and software designed for the information exchange at transmission, emission or reception of it in the form of signals, signs, sounds, moving or still images, or otherwise.

Test plan for reliability – a set of rules that establishes the sample size, the order of testing, criteria for their completion and decision made on the basis of test results.

Threat to information – the leakage, the possibility of blocking or destroying the information integrity.

Time period (uptime) of service – calendar duration from the start of facility operation or after its renovation until its evolution into a boundary state.

Time period of preservation (shelf-life) – calendar storage time and (or) transporting of a facility, for which the parameters that characterize the ability of an object to perform necessary functions are kept within the specified limits.

Troubleshooting period – the time interval that is a part of the operational lifetime spent on unplanned repairs, during which is determined a location of the problem.

Unauthorized actions regarding information in the system – actions that are carried out with violation of rules of access to this information established by the law.

Unloaded reserve – reserve, consisting of one or more reserve items that are in the unloaded state until the execution by them the functions of the major element.

User authentication – recognizing of user (by name and password) stipulating allowability to data access and to the selected mode of its using.

User – a person working directly as an operator of its information system. Each user has the access rights to an individual system.

Violation of system information integrity – unauthorized actions over information in the system, due to which changes its meaning.

Vitality – a property of an object to keep some limited performance in the circumstances of external actions that may lead to the failures of its components.