Peculiarities of reliability provision for complex systems

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Abstract

Reliability is one of the comprehensive indicators of system quality. The issue of security is very complex and responsible throughout the life cycle of the system. The complexity of understanding and evaluation creates quite tangible problems when creating new products due to their specificity. Therefore, in our view, understanding the nature of the processes that determine and ensure reliability is important. The point is that reliability cannot be directly measured and estimated in a real object. The most important indicator of reliability is functionality – the performance by the object of its functions in full. Functioning is ensured by the organization of the work of all effector processes to perform basic functions. The summary makes an attempt to outline the problem and suggests to do so on the basis of decision-making theory. The information may be of interest to designers, technologists, and reliability specialists.

Keywords: System; reliability; problem; quality; functionality; technology.

1. Introduction

1.1. Reliability

Reliability is one of the most important indicators of system quality. The issue of security is very complex and responsible throughout the life cycle of the system. Therefore, in our view, understanding the nature of the processes that determine and ensure reliability is important. The point is that reliability cannot be directly measured and estimated in a real object [1]. By definition [2] reliability is ”The property of an object to secure in time within the set values all parameters that characterize the ability to perform the necessary functions in the specified modes and conditions of use, maintenance, storage and transportation”. Moreover, ”Reliability is a complex property, which, depending on the purpose of the object and the conditions of its use
may include faultlessness, durability, maintainability, safety and certain combinations of these properties.” Specifically, reliability is measured by the faultlessness, durability, maintainability and storage.

Therefore, the most important indicator of reliability is functionality – the performance by the object of its functions in full. Functioning is ensured by the organization of the work of all effector processes to perform basic functions. This means that the design of the product must ensure a stable flow of electrical, chemical, thermal, hydraulic, gasdynamic, etc. processes required to perform its essential functions. Since there are practically no stable processes, the values of their parameters must be within a certain tolerance.

1.2. Functionality

Functionality is formed when designing the product design. Obviously, depending on the specifics of the project, the requirements for the operation, the state of science and technique, technology, cost, etc. Various possibilities are created for the laying of reliability. Most often the optimum level in each case is reached. This level can be called the optimal level of design reliability.

In manufacturing, despite the fact that the design took into account possible manufacturing technologies and, to some extent, the possible impact of manufacturing technologies, due to realities, we get slightly below the level of reliability. This level can be called the level of technological reliability of a new product. Based on practice, especially for mechanical systems, there is a grace period during which some increase in functionality and reliability can be observed.

With the emergence of new scientific advances, new materials, improved technologies, there is an opportunity to increase the design $\Delta_c$ (up to a maximum of 1.0) and technological reliability $\Delta_m$, which can be considered as a reserve for improving reliability.

During the operation of the product under the influence of external factors and internal processes, there is a change in the parameters of functioning, and hence reliability. Depending on the design, manufacturing quality, serviceability and quality of service, the intensity of the changes can vary greatly. It may stabilize or decrease. The organization of quality maintenance and normal operation, protection against overload and “human factor” allows to increase the level of operational reliability, the reserve of which can be designated $\Delta_e$.

The qualitative structure of reliability ensuring can be represented as follows:
- at the design stage, the possible or optimal reliability of the product is laid down, based on the state of science and technology;
- at the stage of product manufacturing, a possible level of reliability is ensured by using available materials and real manufacturing technologies;
- at the stage of storage and delivery, if any, a slight decrease in reliability is possible;
- at the exploitation stage, the level of reliability obtained during manufacture is maintained and, depending on the quality of service and operating modes, is gradually reduced;
- once a critical level is reached (lower point for operating settings), the product is taken out of service. This structure is presented below (see Fig. 1).

It is difficult to approximately or relatively estimate such reductions, but it is possible from experience or from accumulated data, but it can take a lot of time. More realistic to estimate by
Fig. 1. The structure of reliability ensuring, where: $\Delta c$ – decrease due to inability to achieve 100% reliability at the design stage; $\Delta m$ – decrease due to insufficient (real) technological level of manufacture; $\Delta e$ – decrease due to not ideal service and exploitation level.

conducting a comparative step-by-step analysis. Such analysis will make it possible to determine the reliability increase reserves, and in extreme cases, the directions of its increase.

It is more promising to carry out, based on the results of this analysis, special studies regarding the search for the optimal design, analysis of constructive solutions options, use of new materials, advanced technologies, service and exploitation conditions improvements, decrease of the "human factor" influence. Moreover, such practice already exists. For example, on the statistic an about 70% of world emergencies of ocean vessels were corollary of an incorrect crew effects [3]. The certain analogy is watched and in reliability providing.

2. STRUCTURE OF RELIABILITY

Reliability can be most accurately evaluated by exploitation data, but it takes a lot of time and the product becomes outdated at the end of the study, and most likely it will be time to replace it with a more modern one. Accelerated tests give reliable results, take less time, allow you to make changes to the design and technology, evaluate and increase reliability at the same time, but they are quite expensive, and most importantly, not all products can be manufactured in sufficient quantities and put to the test.

Many manufacturers usually conduct such tests, especially if this is a new series. Naturally, the importance and value of the information obtained this way is difficult to overestimate, and it is desperately needed to create new reliable products.

As indicated above, reliability cannot be estimated by directly measuring any setting. In fact, reliability is determined by the availability of functionality. And, since this ability may accidentally disappear (the product works or does not work), its presence can be estimated by the probability that the product will work without failure for a given time. This prognosis is the main characteristic of reliability. But this characteristic is also impossible to measure. Therefore, the moment of functionality loss is used – a failure, which is easy to determine due to the lack of basic settings that characterize the product (system) functionality. And it can be estimated by the probability of the opposite event – the appearance of the first failure at a t point in time.
And, since the moment of time can be different, it is important to have a distribution $P(t)$ of the probability that the product at time $t$ will be serviceable and will perform its functions.

$$P(t) = P[t_f > t]$$ (1)

If at the time of creating the product design we will have a distribution of the function $P_i(t)$ for all $i$ elements, then the task of creating a reliable design becomes quite certain. However, even if we have the reliability of the elements, then in the system of constructive combination of elements there is no guarantee that the distribution of failure-free elements remains unchanged. Because in this case the mutual influence of the elements in the system will be new (different), which means that the operating conditions will change and $P_i(t)$ will also change. Moreover, for different types of systems, such changes are very different. For example, for electronic systems, it is possible to reduce them, but for mechanical systems, the influence is quite significant. Moreover, such practice already exists. For example, on the statistic an about 70% of world emergencies of ocean vessels were corollary of an incorrect crew effects [3]. The certain analogy is watched and in reliability providing.

3. **Decision-making support task**

Let us consider how at the design stage it is possible to take into account the influences and design features, as well as the main processes on the reliability of operation. First, we note that the design of new products does not start from scratch. Over thousands of years of existence, human-kind has accumulated experience, knowledge and information about a huge number of products, their functioning and about the processes that occurred between their elements. In fact, while forming a product, the draftsman relies on the experience of creating similar technical systems, design practice and methodology, the achievement of science and technology, well-known manufacturing technologies, etc. Of course, a priori, you can qualitatively evaluate the design perfection, its working ability, tendency to critical changes, strength, mutual influence and much more.

Design is a classic decision-making support task [4, 5, 6, 7, 8]. The problem is very complex with a great deal of uncertainty, despite the vast experience gained in creating such products. The problem is complicated by the influence of many factors on the functioning, reliability, manufacturing technology, service efficiency and operation. In this case, it is necessary to create a design that would ensure the functionality of the product and at the same time have high reliability, which can be assessed by continuous operation or accelerated testing. If, at the same time, one piece or an assembly failed, it was necessary to change the design of the piece and its environment or the manufacture technology, which required both time and money, but did not guarantee a high result.

The existence of modern powerful computer-aided design systems allows you to carry out design in stages, or rather, to break down the process of creating a structure into a number of stages, and develop possible options at each of them. Then, conducting a comparative analysis, make a decision on one or two of the best and then, at the next stage, deepening the development designs, consider its options and so on. The process of dividing into stages allows you to move from solving one complex problem with a complex multifactorial external influence and complex internal interaction to a number of distinguished, less complex problems. These are smaller problems associated with the possibility of providing some function, organizing some process
or design for the previous organization of a complex process. The options obtained by such a partition are compared and when making the optimal decision regarding one of them, they will make it possible to move on, but only in the best direction. In this direction, options for solving the subsequent small problem are again created and, because of comparative qualitative analysis, a decision is made to go further in a certain best direction. At this moment, the difficulty again arises in that, with such uncertainties, it is rather difficult, according to the classical theory of decision-making, to determine an evaluation criterion, build an objective function and make a decision according to the criterion value.

The breakdown into stages allows us to examine extremely narrow and important problem, the solution of which distinguish the most prospective direction. As for the performance criterion to select from the small options number quantitative analysis is often enough, it should be conducted by a highclass specialist according to the expert assessment method. If it is necessary, the invitation of several experts is possible.

For example, firstly, options of the conception of the future project are formed and then, by analyzing the options and conditions selected the best one. Options of terms of reference are developed according to the best conception. The selected terms of reference are sent to potential developers and manufacturers who send technical proposition. Among the options of technical proposition is selected the best and the contract for creation is concluded. Further, we examine possible constructive assuring for the needed general functionality.

Depending on the type of construction, the possible constructive assuring of processes and the main functional organization, according to each of them phased details are examined up to the complete formation of the entire structure. Of course, for each unique system can be built personal logically stages sequence. The more detailed such sequence is, the more accurate it will be possible to make a decision at the each stage and the deeper will be the elaboration of construction and the easier will be to make the right decision in each particular case.

For greater guarantee of quality, they conduct a full elaboration in several directions according to optimal solutions at some of the first stages. After the finished projects complete analysis with the advent of new ideas, they go back several steps and go to the end according to the new direction.

At the place of production, by analogy the resulting project is analyzed and considered options of production technologies. The options are considered in stages and agreed with the project designers. Here there can be options of manufacturing techniques, options of materials, technology of materials changing properties, technology of ensuring accuracy, technology of materials optimal connection and assembling. Some technology options may require construction changes. Decisions are made and the new branch of successive stages is being worked out.

The final decision remains lay with economic indicators. The cost factor can be taken into account at each stage depending on the requirements, the intended product use, competitiveness, the cost of manufacture and operation, the strategy of the use and redistribution between the manufacture cost and use.

The well-known formula is the higher cost of manufacturing of high-quality and reliable product, the lower the cost of repairs during exploiting and vice versa. The second formula is the product reliability as a whole is determined by the reliability of the most unreliable element. It is considered that the most effective option when all elements have the same reliability. It is almost impossible to achieve such reliability, but it is necessary try to balance.

Because of the sufficiently long period of using products and the assessing of their reliability,
humanity has developed a number of methods and technologies for improving reliability. They make it possible to increase the reliability of complex systems under equal conditions. To such technologies can be included:

- reservation;
- module technologies;
- standardization and unification;
- reconstruction;
- maintainability.

Examine these directions of improving reliability. Due to operating conditions, constritive features, material properties, manufacturing technology, it is not always possible to achieve the sufficiently high reliability of an element. If according to the operating conditions, failure is not allowed for the period of the system use, then the reliability of this element is forced to increase structurally due to introduce redundancy. This method is called reservation. The essence is that constructively instead of one insufficiently reliable element, a block of several such elements is set in parallel. Depending on the type of reservation, if one of them has failure, it automatically replaces the second one without interruption of operation or all of them work in a less loaded mode. This allows increase the system reliability due to structural complications and increasing of weight, size and cost.

Almost every technical system has several functional groups of elements that can be divided into separate nodes and developed as separate functional constructive products such as modules. This allows you to develop, lead up and produce them separately at specialized enterprises, unify them or standardize them and use them later on similar products as functional elements. This technology allows to get quite reliable, highquality products, convenient to use and easily replaceable after refusal, and, most importantly, this module is convenient to use in all technical systems where such functionality is necessary.

In the case when interruptions of operation are allowed during operation, system restoration by repair is widely used. The most convenient repair is the replacement of an element that has lost operability. At the same time, the quality of the restoration is higher, and the recovery time is significantly less, and no special equipment is needed, and a high qualification of replacement is not needed. If it is decided to use such a method, then at the design stage the design is developed so that the replacement can be done without complex repair operations. In other words, they lay a fairly high maintainability. Maintainability is characterized by adaptability to the restoration of unreliable elements of the technical system. This provides convenient access to an element that has failed, simplifying the search for a malfunction, or even equip it with special devices for determining and localizing a malfunction, the manufacturability of replacing an element without the need for complex settings or devices, and protecting against the influence of an element that is out of order, adjacent or dependent on other element or system as a whole. If the system is remote from repair bases or is composed of unreliable elements that may not be available in such bases, it is necessary to have the optimal number of spare parts for replacement.

The widespread use of standardized and unified modules significantly increases maintainability, and, therefore, the reliability of the system. A good example is the modular design of IBM personal computers.

Another direction of increasing the reliability of systems is their constructive protection against incorrect or harmful effects. This primarily relates to the maintenance staff, as well
as, as far as possible, from the negative impact of adverse external factors. This can be improper maintenance, overload, improper assembly and other adverse effects that can lead to abnormal functioning, and even to the failure of the system or a significant deterioration in its functioning.

At the operational stage, the inherent reliability is realized and confirmed. But, depending on the level of service, operating conditions, the influence of the "human factor” reliability changes. Therefore, even at the design stage, constructive properties are laid in accordance with the most stringent conditions for the product to perform its functions. Rules and maintenance instructions are developed, the material base is formed to ensure normal functioning throughout the life of the system. Specialized service centers are being created to provide quality service and prevent unqualified influence.

In order to maintain reliability, routine maintenance and repairs are being introduced. Preventive repairs with the obligatory replacement of unreliable elements at specialized service stations can improve reliability and eliminate losses from possible failures. Many manufacturers create branded service centers that monitor the status of their products, collect information about failures and malfunctions. This information is used to assess reliability and is subsequently used to constructively and technologically increase the reliability of new products. In the event of a systematic occurrence of breakdowns, the company forcibly recalls the corresponding products to service centers and replaces unreliable elements.

4. Conclusions

Ensuring reliability is a very complex, expensive, responsible and lengthy process. Understanding the essence of reliability laying allows even in conditions of uncertainty to determine it and move in the desired direction. Using the principles of decision support for their phased use and the logic of qualitative analysis will allow us to a priori evaluate the level of reliability of possible options. The information may be of interest to designers, technologists, and reliability specialists.

5. Conflict of interest statement

No part of this investigation has competing interests.

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