Forecasting and operational assessment of the quality of repaired units

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Abstract. Evaluation alone is not enough to improve product quality. It is necessary to have not only the estimated indicator itself, but also to declare the factors that influence the formation of quality and to investigate this influence. Only then does it become possible to carry out quality management. To study the quality of repaired products, we use the economic and statistical method, which is as follows. Product quality is considered in two aspects: production and consumer. Manufacturing quality is a set of product properties (physical, chemical, physical and mechanical, etc.) obtained by it in the process of manufacturing or repair. The consumer quality of products manifests itself in the process of consumption (operation) and is determined by the cumulative impact of all characteristics of production quality and conditions of consumption. With the help of the correlation level, two main tasks can be solved: operational quality assessment at the stage of production (repair), based on predicting the consumer quality of the projection according to the known values of its production quality indicators; management of the production quality of products in accordance with a given level of its consumer quality. The most characteristic indicators of the production quality of the repaired units are the errors in the dimensions of the shape of parts, the relative position of their surfaces, the size of the washed out links of the dimensional chains of mechanisms, the physical and mechanical properties of materials, etc. At the repair enterprise, by means of appropriate measurements, the values of the indicators of the production quality of batches of products are determined. Then, in operation, these products are monitored in order to determine their consumer quality. The consumer quality of repaired products can be expressed by a number of indicators, but the most expedient is the use of such an indicator as winding to the first failure caused by aging processes (wear, fatigue failure, etc.). Considering the above, research aimed at predicting and quickly assessing the quality of repaired units is an urgent problem.

1. Introduction
The unit is considered as a complex product consisting of a number of subsystems. The study of the relationship between production and consumer quality is carried out separately for each subsystem [1-6].

As a result of research, we obtain information about the values of the indicators of the production quality of subsystems and the values of the operating time of these subsystems to failure. Based on this information, mathematical models are built that reflect the correlation between the production and consumer quality of individual subsystems. After that, a general mathematical model of the system as a
Research and assessment of the quality of repaired products are considered on the example of an engine [7-13].

2. Research results

The production quality of engines is finally formed during the assembly process (running-in of units is not considered). The input of the assembly process is the state of the parts, which is characterized by a set of primary indicators $x'$. The production quality of the assembled product is characterized by a set of complex indicators $x''$ that depend on the primary and quality of assembly operations. Complex indicators carry more information about the state of the object, but it is not always possible to measure them. In these cases, primary indicators are used to assess production quality.

In quality research, the engine is considered as a system consisting of a number of subsystems. Each subsystem is considered a simple product. Indicators of its production quality are determined, a connection with consumer quality is found, connections with other subsystems are analyzed. Figure 1 shows a diagram of the study of the quality of a complex product.

![Diagram of quality research](image)

**Figure 1.** Scheme of quality research: $x'_i, x''_i$ – the aggregate, respectively, of the primary and complex indicators of the production quality of the $i$-th subsystem ($i = 1, 2, ..., n$); $Y_c$ – a set of indicators of the consumer quality of the system; $Y_{ci}$ – a set of indicators of consumer quality of the $i$-th subsystem; $A$ – operator forming the general indicator; $I$ – product assembly; $II$ – product operation.

The main indicator that objectively characterizes the consumer quality of engine repair is the value of its operating time to failure of one of the subsystems caused by aging processes.

Often, an economic assessment of the quality of such complex products as an engine cannot take into account a number of important properties; therefore, additional indicators are required, on which appropriate restrictions are imposed.

For engines, such indicators are power, stability of operation at low speeds, oil pressure in the line, noise, vibration, the content of harmful impurities in exhaust gases, the fatigue strength of parts, etc. is considered suitable and its quality is not evaluated.

The operating time of the system to failure under the conditions of a specific implementation is determined by the operating time of the "weakest" subsystem. Having received an equation for this subsystem that connects its production and consumer quality, a mathematical model is built for the entire system. To solve this problem, the Monte Carlo method and methods of planning experiments are used.

The general method for studying the quality of engines is as follows:

1. The nomenclature of the main and auxiliary indicators characterizing the consumer quality of the system is determined.
2. Within the system, separate subsystems are distinguished and their mutual connections, transmission channels and the nature of signals are considered.

3. Indicators of the production quality of each system are determined.

4. Correlation equations are built connecting the consumer and production quality of the subsystems.

5. Indicators of consumer quality of the system as a whole are determined.

6. A mathematical model is constructed that reflects the dependence of the indicators of the consumer quality of the system on the indicators of the production quality of the subsystems.

7. In accordance with the existing requirements, restrictions are imposed, but the indicators of the consumer quality of the system and the permissible values of the indicators of production quality are determined.

The working conditions of the subsystem, and, consequently, the terms of their service are determined by both internal and external factors. Internal factors are indicators of the production quality of the subsystem itself, external factors are a manifestation of the influence of the environment. A group of factors characterizing the quality of repairs is distinguished from the total set of factors for the study.

Considering the engine as a complex product, the following subsystems can be distinguished according to their functional characteristics: power supply; gas distribution; ignition; cylinder-piston group; connecting rod and piston group; crankshaft - main bearings; clutch; lubricants; cooling. For each subsystem, a nomenclature of indicators is determined that characterize, mainly, their production quality; it goes to the baseline information about the production and the consumer as this subsystem, and then constructed a mathematical model:

\[ \bar{y}_i = f(x_{i1}, x_{i2}, \ldots, x_{in}), \]  

where: \( \bar{y}_i \) – the average value of the consumer quality indicator of the \( i \)-th subsystem; \( x_{i1}, x_{i2}, \ldots, x_{in} \) – indicators of the production quality of the \( i \)-th subsystem.

After obtaining such mathematical models for all subsystems, the next stage is performed - the construction of a mathematical model of the system as a whole.

To determine the operating time of the entire product (\( L \)) by the known values of the operating time of its subsystems (\( L_i \)), the Monte Carlo method is used. The essence of this method lies in the use of random numbers earned in one way or another with a given distribution law.

The solution of the problem of constructing a mathematical model of the system as a whole is carried out in two stages on a computer. At the first stage, an algorithm is developed for determining the operating time of the system (\( L \)) for given urinations of indicators of the production quality of individual subsystems (\( x \)). At the second stage, by changing the initial data (\( x \)), the corresponding values of the operating time of the system (\( L \)) are determined, and on the basis of this information, the mathematical model of the system is already developed directly.

To perform the first stage, it is necessary to have mathematical models that reflect the relationship between the production and consumer quality of all product subsystems:

\[ L_i = f(x_{i1}, x_{i2}, \ldots, x_{in}). \]  

After that, you need to know the scheme of failure, i.e. diagram of the conditional connection of elements in the system.

The operating time of the unit before the first failure of any subsystem is taken as an indicator of the consumer quality of the engine. That is, we are dealing with a serial connection of elements. The operating time of each specific engine is determined by the operating time of its "weakest" subsystem, i.e:

\[ L = \min(L_1, L_2, \ldots, L_n), \]
Where: $L$ – engine operating time to the first failure; $L_1, L_2, \ldots, L_n$ – the value of the operating time of its individual subsystems.

The block diagram of the algorithm for determining the engine operating time is shown in figure 2.

![Block diagram of the algorithm](image)

**Figure 2.** Block diagram of the algorithm for solving the problem of modeling a system by the Monte Carlo method.

At the second stage, for the operational assessment of the quality of the repaired engines, a nomogram was built (Figure 3), which allows predicting the average engine operating time using the known values of two production quality indicators.
To predict the engine operating time in accordance with the value of the indicator $x_2$, the required curve is selected on the graph and the value $L$ is determined from the value $x_3$. An operational assessment of the quality of repaired engines is carried out on the basis of predicting their operating time. Having determined, based on the results of production control, the average values of the production quality of engines repaired at a given enterprise, it is possible to assess the quality of products by predicting the operating time.

3. Conclusion
Forecasting methods make it possible to determine the resource distribution of the elements of machines and assemblies depending on the quality of manufacture (repair), operating conditions and operating modes.

When implementing the above approach to assessing the service life of products, it is necessary to use the following characteristics: fatigue resistance of parts under high-cycle loading; loading of machine parts; wear resistance in specific operating conditions and probabilistic and statistical research methods.

Methods for predicting the durability of machine parts and the durability of units and assemblies in terms of durability of their elements can serve as a scientific basis for determining the suitability of repaired products.

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