Checking the adequacy of the technical and economic model for ensuring a target life of an individual production machine

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Abstract. A number of principles to ensure the reliability of individual production machines have been formulated. A block diagram of the model for ensuring the gamma-percentage target life of the individual production machine parts has been built on their basis. To assess the model adequacy, the accelerated operational tests without a test stand base have been proposed. A machine (units, parts) is considered as a system with mutually loaded elements, i.e. self-stand.

Introduction

The machines of individual production (multi-bucket stripping wheel overburden excavator for mining in a specific quarry, a rolling mill for a certain type of rolled metal in metallurgical production, a car of the President of the country, a helicopter and a plane of the President, a Mars rover, as well as the cars of foreign production (Maybach (2005), Rolls-Royce (2008), Cadillac DTC (2009), Ferrari (2010), Bugatti (2011), Lamborghini (2012), Cadillac Elmiraj (2013)) unlike serial machines require a different approach to ensure their reliability [1,2].

If for serial machines of domestic production, great experience in solving the problems to ensure reliability [3-5] has been accumulated since the end of the 60s of the last century, and for the past 50 years they have been engaged in ensuring, improving the reliability of serial machines [6-8], then for the machines of individual production these tasks started being solved from about 2010 to 2016 [1,2].

These or those models (mathematical, technical and economic) are known to be used in scientific research, from the practical point of view, and they make it possible to perform calculations and obtain the necessary results rather quickly [9,10].

In this case, it is required to determine the calculation error for making a decision.

When ensuring the reliability of machines of individual production, a model, the block diagram of which is shown in Figure 1, is used.

A number of principles (2, 3, 4) for ensuring the reliability of serial machines, which are used in the development of a new method for ensuring the reliability of machines of individual production, have been formed. The principles 1, 5, 6 are formulated for a new method (individual production) [1].

The basic principles, used in the method, are as follows.

1. A homogeneous sample is formed from the parts not for their intended purpose, but for a gamma-percentage resource with an acceptable error [11].

2. A set of finite volume is used.
Figure 1. Block diagram of the model for ensuring the gamma-percentage resource of the machine parts of individual production

3. For the set, Weibull’s law is applied without the shift parameter; it is replaced by the minimum first value of the variation series. This replacement is due to the fact that the shift is less than the minimum value of the variational series of the sub-total, which is not correct.

4. The parts with sudden fatigue failures are designed for a target life with a certain margin.

5. Adjacent parts are the parts of the test stand; parts of the whole machine form a stand.

6. For the period of scheduled and application repairs and maintenance, it is necessary to have a backup machine.

A feature of the last 50-60 years of the mechanical engineering development and the applied probabilistic and statistical methods was the processing of significant amounts of information, for example, the samples of 50, 100 and more units (machines, assemblies, parts).

Such methods were widely used to determine the reliability indicators of serial machines [10, 12].
Main part
Methodological materials of the state and industry levels were developed, allowing to process the statistical data on the various products’ reliability properties.

At the same time, the issues of ensuring the reliability of the most important products of individual production (the car and helicopter of the President of the country, a unique rolling mill and overburden excavator, a lunar rover, a rover, etc.), as well as foreign-made passenger cars [2] and the statistical methods necessary in these cases require their own solutions.

The attempts to find the recommendations in this area of science and practice in the technical literature have not showed any results yet (perhaps this is a closed topic).

The key questions in the formation of samples are their representativeness (most often used) and homogeneity.

A sample is called representative if it sufficiently well represents the characteristics of the general sub-total.

The sample is homogeneous if each sample object has a main parameter that is the same (or almost) with other sample objects [11].

The sub-total or a sample from it will be homogeneous if the main parameter, for example, the target life is the same (with some error) with other details.

Figure 2 shows the examples for the machine parts.

![Figure 2. Machine parts of serial and individual production](image)

In case of using one gear (Figure 3), the sample size will be determined by the number of its teeth. Then these teeth form a sample both by the main parameter and by the purpose.

If there are two or more gears in the unit (gearbox) (Fig. 3, b, c), the sample can be formed by the teeth of two and three gears.
Figure 3. Gears of individual production: a - one gear, b - double block of gears, c - triple block of gears.

At the same time, the gamma percentage resource of the part should be used as the main parameter. Then the homogeneity of the sample (sub-total) will be determined by the same gamma percentage resources of the details (within the acceptable error)

$$T_l \gamma_1 \approx T_l \gamma_2 \approx \ldots \approx T_l \gamma_n \approx T_l t,$$

where $T_l t$ – is the target life to the limit state of the part.

The main condition for ensuring the same main parameters of parts with sudden failures - resources (single-individual production machines) - is the calculation by the Wohler-Sorensen-Kogaev formula based on the experimental initial statistical data of fatigue strength and loading.

Figure 4. Probabilistic resource distributions of the samples and sets of parts with fatigue sudden failures: 1-sample; 2-set

Figure 4 shows that for the distribution of the sub-total, the resource span is greater than the sampling span.

The algorithm for determining the parameters of the sample and the sub-total is shown in Figure 5.
Information for calculating the resource of the part is shown in Figure 6.

The entire composition of machine parts should be divided taking into account the effects of part machine failures (Table 1).

Table 1. Influence of types of damage to parts on the reliability of the machine (unit).

| Parts with sudden failure | Parts with drift failure | Unloaded details |
|--------------------------|--------------------------|------------------|
| Fatigue                  | Wear, fatigue            | No failure       |
With regard to a serial machine, the indicators for its reliability properties are used, both for the machine as a whole and for the units and parts. In addition, the complex indicators are used: availability and technical utilization factors. The same indicators are determined for an individual production machine.

An important place in the system of ensuring the reliability of individual production machines is occupied by the tests, which should confirm the calculated resources of the machine parts (assembly).

Analysis of various types of tests showed that the most effective type is the operation of a machine (unit), almost every part is tested and at the same time serves as a loading element for another part (self-stand machine).

In this case, it is necessary to assess the adequacy of the model to the experimental data.

A certain difficulty is the duration of the experiment (10-20 years) to confirm the adequacy of the calculated results to the experimental data.

To solve this problem, it is advisable to use the accelerated tests without a stand base and increased loads, but only under operating conditions and by reducing the calendar operating time of the tested machine [7].

The positive side of such accelerated tests in time is the fact that the strength and loading correspond to the design modes of units and parts. Such tests are operational, and the results obtained (in contrast to stand tests with increased loads) do not require recalculations and are more reliable [7].

In this case, the machine (units, parts) is considered as a system with mutually loaded adjacent elements, i.e. as a stand [1].

This is the first time we have come to this conclusion, having been involved in machine reliability for over 50 years [3].

![Figure 7](image_url)

**Figure 7.** Variants of neighboring nodes for the self-stand

Figure 7 shows that, for example, for a part of a car (a), the transmission is a loading element of the engine; for the drive axle, the loading unit is a cardan drive.

Calculating the machine’s target life:

| Not diagnosed | Are diagnosed, the failures are prevented by the planned replacements |
|---------------|---------------------------------------------------------------------|
| Cause machine failure | Do not cause machine failure |

Typical case,
for 10 years of operation:

\[ T_d = 10 \text{ years.} \]

\[ D_y = 253 \text{ days a year.} \]

\[ T_h = 8 \text{ h work in 1 day.} \]

\[ T_d = 10 \cdot 253 \cdot 8 = 20240 \text{ h;} \]

2530 days in 10 years.

Accelerated in time testing machine:

\[ D_y = 360 \text{ days a year.} \]

\[ T_h = 23 \text{ h work in 1 day.} \]

\[ T_{sy} = 23 \cdot 360 = 8280 \text{ h a year.} \]

\[ T_{sy} = 23 \cdot 360 = 8280 \text{ h a year.} \]

\[ T_{s1} = 20240: 8280 = 2.45 \text{ year.} \]

Acceleration: 10: 2.45 = 4.1 times.

Consequently, one of the two manufactured machines according to the same drawings and technologies is subjected to the operational tests for 2.5 or 5 years with the recording of operational information about failures, repairs, etc. [12].

Perhaps during these five years of operational tests of one (second) machine, it will be necessary to ensure an increase in the target life of parts, machine components by changing the design and manufacturing technology [9,13].

Figure 8 shows a diagram of ensuring the reliability of the test machine No. 1 and the main machine No. 2.

![Diagram showing scheme of ensuring reliability](image)

**Figure 8.** Scheme of ensuring the reliability of the main and backup machines
Summary
Thus, to ensure the reliability of an individual production machine, when at first glance there is no possibility of using the proven probabilistic-statistical and other methods of ensuring the reliability of serial machines, there is a real opportunity to apply the above-mentioned method.

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