Ensuring assigned fatigue gamma percentage of the components

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Abstract. The problem of increasing the efficiency of the construction machines functioning continues to be relevant in modern conditions. The downtime of construction equipment, in particular, of a single-bucket excavator (SBE), leads to a violation of the terms of work and to significant economic losses. One of the most loaded elements of a single-bucket excavator is a boom. Increasing the reliability of its work reduces the number of the machine failures greatly, and as a result reduces the cost of repairs and equipment downtime. The gamma-percentage fatigue life of the components, in particular, a single-bucket excavator boom, must correspond to the resource before discarding the machine. To prevent failures, it is necessary to increase the gamma-percentage fatigue life of the boom to the optimum value by changing the steel grade and the geometric characteristics. This will reduce the repair expenses and the damage from the downtime of the excavator as well as the mechanized machinery complex associated with its operation, thereby determining the relevance of the work presented.

Introduction

In the resource calculations, the initial data obtained from the volume samples \( n = 10 \div 100 \) are used, although there may be thousands or even millions of machines, components and parts in operation that form the general aggregate of the final volume.

Considering the significant number of parameters to be estimated, it is necessary to improve the method of providing the specified fatigue gamma-percentage resource of the single-bucket excavator parts using the transition sampling — the totality.

In the present work we use the characteristics of a model for increasing and optimizing the fatigue gamma percentage of the details of a single-bucket excavator boom for the transition from the selective initial data to the parameters of the total strength and operating stresses [1]. The model obtained should meet the following requirements:

To possess the ability to use the simulation to obtain the totality of the values of the resource details, endurance limit, tensile strength and load \( (n = 10 \cdot 100) \).

To imply both experimental data on strength and loading, and technical and economic parameters of the machine [2].

To allow calculation and optimization of the part gamma percentage, both for the sample and for the aggregate.

Main part
On the basis of the experimental and theoretical studies carried out, a model to ensure the fatigue gamma-percentage resource of the part using the example of a single-bucket excavator has been developed. The model block diagram is shown in Figure 1.

**Figure 1.** The model block diagram for ensuring the shovel boom fatigue gamma-percentage resource.

The following designations are used in the model: $C_i$ is the $i$-th unit cost per unit of a machine output; $i = 1, \ldots, k$; $k_i$ - the parts types number; $P_{bi}$ - the boom prices; $P_{tech}$ - the excavator technical performance; $C_r$ - restoration costs; $R_{cv}$ - the cargo volume ratio in the bucket; $C_{sdr}$ is the soil density reduction coefficient; $P_{tp}$ - the excavator theoretical performance; $C_b$ - bucket capacity; $t_c$ - cycle time; $D_{ebf}$ - damage from downtime due to the excavator boom failure, as well as the associated mechanized complex; $C_r$ - costs for the boom recovery after failure; $M$ - is the mechanic-repairman tariff rate, $T_r$ is the idle time to repair, $C_{add}$ is the additional costs; $\psi_{wi}$ is the coefficient taking into account deformations as a result of thermal exposure; $k_{si}$ - coefficient taking into account the sharp changes in the surface radius; $\Delta_i$ - coefficient taking into account the surface state; $\varepsilon_{ni}$ - coefficient taking into account the cross section absolute dimensions effect on the part’s endurance limit; $k_{opti}$ - the part endurance limit change total coefficient; $d_f$ - is the damage amount resulting from the fatigue deformations; $N_0$ is the total number of cycles; $f_i$ is the loading frequency; $R_m$ - the resource obtained by means of modeling using the Weller-Serensen-Kogoaev formula; $\sigma_{wi}$ - steel endurance limit; $\sigma_{1pi}$ - the endurance details limit; $m_{2i}$ - fatigue curve exponent; $\beta_i$ - roughness; $c$ is the coefficient of
transition from hardness to strength; HB - Brinell hardness; \(a_{\text{Trs}}, b_{\text{Trs}}, c_{\text{Trs}}\) - parameters of scale, shape and shift for the resource calculated by the sample; \(A_{\text{Tre}}, B_{\text{Tre}}, C_{\text{Tre}}\) - similar parameters of the resource selection extreme members; \(A_{\text{Tra}}, B_{\text{Tra}}, C_{\text{Tra}}\) - similar parameters of the resource aggregate; \(T_{\text{pr}\gamma\text{opt}}\) is the optimal gamma percentage resource.

This model is a system consisting of seven blocks: I - parameters affecting the machine technical performance; II - parameters affecting the unit costs; III - parameters affecting the repair costs; IV - parameters affecting the fatigue limit change coefficient; V - parameters related to the part’s strength and load; VI - parameters required for modeling the resource details for the sample data; VII - parameters required to determine the fatigue gamma-percentage resource details.

The developed model makes it possible to determine the fatigue gamma percentage resource of a part not by sampling data, but by the aggregate parameters, and to optimize the specific total costs, which ultimately determine the optimal value of the part’s reliability function [4].

As a result, the developed model for ensuring the fatigue gamma-percentage resource of a single-bucket excavator will optimize the boom’s trouble-free operation probability.

In the present paper, a method for calculating the fatigue gamma-percentage resource of a single-bucket excavator for a set of finite volume using an analytical method for determining the Weibull distribution law parameters has been developed. The calculation was performed according to the algorithm presented in the Figure 1.

**Figure 2.** The algorithm for determining the refined discrepancy between the minimum resources for a sample and an aggregate

The simulated values of the resource \(T_{\text{pr}}\), obtained using the proposed algorithm, are approximated by the three-parameter Weibull law, and the parameters of the population distribution are determined using the analytical method. Then the minimum values of the sampling resource and the aggregate are compared [3].

In the presence of selective data, it is necessary to solve the problem of a simpler transition from a selective resource to an aggregate resource, especially if the aggregate is the volume \(N_c = 103 - 106\).
The algorithm (Figure 2) in the Weller-Serensen-Kagayev formula indicates the product of the coefficients by the factors influencing the endurance limit of the sample. This coefficient shows the discrepancy between the extreme values of the factors for the sample and the population.

\[ \prod_{i=1}^{n} K = k \cdot \psi \cdot \sigma_{1} \cdot \beta \cdot \varepsilon_{1} \]

**Figure 3.** The algorithm for determining a simplified discrepancy between the minimum resources for the sample and the population.

Figure 3 shows a graph comparing the discrepancies between the refined and the simplified methods.
Figure 4. Comparison chart, the refined (1) and the simplified (2) algorithm

Thus, the analysis of the refined and the simplified methods for determining discrepancies between the smallest values of the sampling resource and the aggregate shows minimal (0.001-14%) differences in the results, which provides the possibility of a fairly correct replacement of methods. Usually the study aims to find the optimal result, so the optimal value of the FOP can be obtained by considering the various options for the manufacturing of the excavator boom.

As possible options associated with changes in the strength characteristics and the effective voltage in the dangerous section of the boom, it is proposed:
1. To increase the wall thickness of the boom (from 8 to 14 mm).
2. To replace the steel grade (from St3 to 09G2S).
3. To increase the boom’s section.

The obtained values of the minimum resource $T_{\text{pmin}}$, the failure-free operation probability (FOP) $P_i$, the price of the component $P_{ci}$, the total costs are given in the table.

Table 1. Values of the failure-free operation probability of the boom for 20 thousand rubles, the price of the boom $P_{bi}$, the repair expenses $E_{ri}$, the total expenses $E_{toti}$.

| № | The steel type | $T_{\text{pmin}}$, [h] | $P_i$ | $P_{ci}$, [rub] | $E_{ri}$, [rub] | $E_{tot}$, [rub] |
|---|----------------|---------------------|-------|-----------------|----------------|-----------------|
| 1 | St3 10 mm      | 542                 | 0.100 | 98900           | 143010         | 241910          |
| 2 | St 3 12 mm     | 5730                | 0.025 | 118680          | 176245         | 294925          |
| 3 | St 3 14 mm     | 6035                | 0.422 | 143295          | 119520         | 262815          |
| 4 | St 3* 10 mm    | 5641                | 0.200 | 118680          | 143744         | 262424          |
| 5 | St 3* 12mm     | 12612               | 0.216 | 132416          | 153286         | 285702          |
| 6 | St 3* 14mm     | 13996               | 0.850 | 153954          | 32693          | 186647          |
| 7 | 09G2S 8mm      | 19500               | 0.999 | 189951          | 276            | 190227          |
| 8 | 09G2S 10mm     | 24091               | 1     | 220000          | 0              | 220000          |

* - increase in cross section by 20%.

The figure 4 is based on the table data (Figure 4). Optimization of FOP for a boom life of 20 thousand hours (depending on the boom price $P_{bi}$, costs for the failures elimination $E_{ri}$ and the total expenses $E_{tot}$). For a more accurate determination of the optimal value of FOP Popt, the obtained dependences were approximated [4, 5].
FIGURE 5. Optimization of FOP for a boom life of 20 thousand hours (depending on the boom price \( P_b \), costs for the failures elimination \( E_f \), and the total expenses \( E_{tot} \)).

Summary
As a result of calculating the probability of failure-free operation \( P = 0.999 \) for 20 thousand hours, the best option is a construction of steel 09G2S with a wall thickness of 8 mm.

The economic effect of the single-bucket excavator EK-14 boom fatigue gamma percentage ensuring is obtained due to the reduction in the number of failures and the corresponding costs for their elimination taking into account the losses from the excavator idle. This effect is calculated for the optimal boom production option.

As a result of the research, it was established that the probability of failure-free operation of the boom with an increased gamma percentage resource is \( P = 0.999 \), which corresponds to the resource \( T_r = 19,500 \) h. At the same time, the gamma percentage resource for the serial boom was 35.9 times smaller. The annual economic effect for a boom with an increased gamma percentage resource is 5,841 rub. for one excavator or 292,050 rub. for the annual production of excavators in the amount of 500 units.

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