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Study of the regularity of wear influence on the service life of cutting elements of bulldozers' working bodies

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Abstract

Our mathematical model describes the regularities of blade wear and takes into account the influence of different operating modes of a bulldozer when dealing with diverse soils that have different degrees of abrasiveness. When calculating the probability of failure-free operation of the bulldozer cutting elements (blades), which depends on the maximum load, it was found that the probability of failure-free operation at an operating time of 600 machine-hours is 0.7...0.75 – for soil category I; 0.5...0.55 – for soil category II; 0.3...0.35 – for soil category III. Comparison of failure-free operation probabilities has made it possible to establish that with an increase in soil density, failure-free operation probability drops by 30-40%, which suggests a significant impact of soil density on reliability of the bulldozer working equipment. In addition, this mathematical model of the total probability allows us to obtain a theoretical description of changes in failure-free operation probability of the bulldozer equipment during working processes, changes in the service life of a bulldozer blade, and taking into account the properties of the blade material. The service life of a bulldozer cutting element can be estimated by its wear, structural features of the material, geometric parameters (thickness in particular), and machine operating modes. It has been established that the regularity of changes in the service life, due to bulldozer blade wear, is exponential. The higher the soil category is, the lower the wear is, and hence the service life of a bulldozer working body. The dependence of the change in the blade service life on the time of its contact with soils of three categories was obtained as well. Thus, the maximum value of a blade service life at the beginning of operation on different soil categories was determined: 450 machine-hours – on soil category I; 350 machine-hours – on soil category II; 280 machine-hours – on soil category III.

Key words: bulldozer, blade, service life, failure-free operation, wear, working equipment, soil category.

Introduction

During the study of bulldozers operation, it was found that a significant number of failures are associated with the failure of working equipment. Besides, according to the data [1, 2, etc.], up to 90% of failures are caused by the rapid wear of the cutting elements of the working bodies (WB).

Bulldozers are known to operate in different conditions. In this case, individual work operations differ from one another by the schemes of applying external loads, so the load of the units is formed independently. Consequently, the statistical characteristics of the workload can generally be constant. It can be assumed, however, that in each case, the amount of accumulated fatigue damage does not depend on the sequence of loading conditions. This makes it possible to represent the operation of a bulldozer consisting of separate typical load modes, which are also determined by certain soil conditions. The bulk of a bulldozer operating time occurs in modes in which its WB performs relatively slow vertical and angular movements. However, the average speed of the latter is low compared to the speed of the machine itself.

Literature review

The results of the experimental studies conducted with the bulldozer's WB in cohesive homogeneous soils show significant high-frequency fluctuations in cutting forces [3]. In real-world conditions, when cutting soil with wide blades, there is not one spall of soil, but a sequence of spalls occurring simultaneously. The vibrations causing this phenomenon cannot be detected due to their damping by the mass of the working equipment.

The numerical characteristics (mathematical expectation, variance, etc.) of the random process of a bulldozer blade's total load are influenced only by the numerical characteristics of the soil strength properties. Due to a rather slow change in the strength properties of homogeneous soils, it is possible to represent their influence by a discrete set of characteristics. In this case, the parameters of soil conditions are immutable in each case.

Bulldozers' WB are known to operate in rather unfavourable conditions. The most noticeable process affecting the durability of the WB is wear and tear. In its turn, bulldozer blades wear mainly depends on the soil abrasiveness, that is, their ability to change the cross-section of the cutting elements. This ultimately leads to their restoration or, in the worst case, to the breakage of the cutting part with the subsequent replacement of the entire blade. Furthermore, the abrasiveness of soils increases with the content, size, and fixed quartz particles (silicon oxide SiO2) [3]. In addition, as shown in [4], with an increase in soil density, the wear of the WB can grow by 5 times (especially with a low content of clay fractions), which negatively affects the service life of the WB blades.

Purpose

Determination of the correlation between service life and wear of a bulldozer blade under various dynamic and alternating loads.

Research Methodology

One of the main indicators of the reliability of the bulldozer WB is the probability of its failure-free operation and service life.

The entire operational load of a bulldozer's working equipment can be divided into categories that are classified by characteristic features [5]. Primarily, it is necessary to consider the following components:

$P(P_{dyn})$ – the probability of blade failure-free operation, depending on the maximum load applied to the blade edge;

$P(h_w)$ – the probability that depends on the value by which the thickness of the blade has changed as a result of wear;

$P(P_w)$ – the probability that depends on the load variable.

Being aware of their influence on the probability of failure-free operation of the entire bulldozer's working equipment, it becomes possible to make adjustments at the stage of a cutting element design.

In accordance with [5], we can find the total probability of bulldozer blade failure-free operation:

$$P_{\Sigma} = P(P_{dyn}) \cdot P(h_w) \cdot P(P_w). \quad (1)$$

As a matter of fact, the probabilities $P(P_{dyn})$, $P(h_w)$, and $P(P_w)$ are interrelated in the following way: when the blade's working surface wears by h_w value, the blade's cross-section changes, as well as its load-bearing capacity. In turn, the latter determines the maximum force on the blade edge it can withstand. The probability $P(P_w)$ also depends on the load-bearing capacity.

Results

As a result of analysing the processes of cutting, ploughing, stopping performed by a bulldozer and its hitting a thoug obstacle, the load on the WB was measured. In addition, we studied the influence of the blade angle in the plan on the maximum force on the blade edge when hitting a tough obstacle.

Fig. 1 shows the graph of the maximum P_{max}=max(R_x) at the cutting edge of the blade when it hits a tough obstacle, depending on the angle of the blade in the plan α for three categories of soil.

Approximating the dependence P_{max}=f(α) shown in Fig. 1, we obtain:

$$P_{max}(\alpha) = A \cdot \sin\left(B \cdot \frac{\alpha - C}{80}\right) + D, \quad (2)$$

where the coefficients A, B, C and D, obtained on the basis of P_{max}=f(α) dependence approximation, are shown in Table 1.

According to [4], we will consider the first 700 hours of blade operation in the soil. Then the wear dependence of the bulldozer blade as a random function of operating time can be generally described as $h(t)=a_u t^{\beta}+b_u$ (Fig. 2). In this equation, the calculations were based on the statistical data obtained by the authors during the the bulldozer operation. It was assumed that the indicator was β=1/2, b_u=0 [6].

Table 1

Coefficient values *A*, *B*, *C* and *D*

Soil categories	*A*	*B*	*C*	*D*
I	250	1,2	5	-10
II	305	1,25	10	20
III	380	1,4	12	50

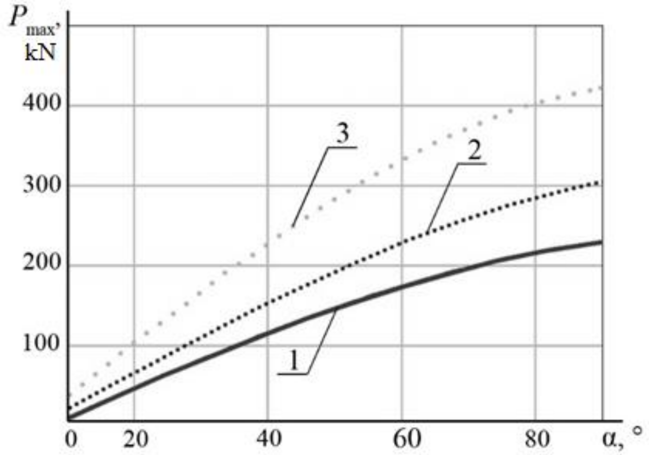

Fig. 1. Dependence of P_{max} on the angle of the blade gripping α: 1 - soil category I, 2 - category II, 3 - category III

The graph in Fig. 2 shows that in the first 50-100 hours of operation, wear is intense and linear. Then the wear gradually quasi-stabilizes, and then after 500-600 hours it starts to increase rapidly. Therefore, the wear rate of the bulldozer blade for each category of soil can be defined as $v=dh_w/dt$ [7].

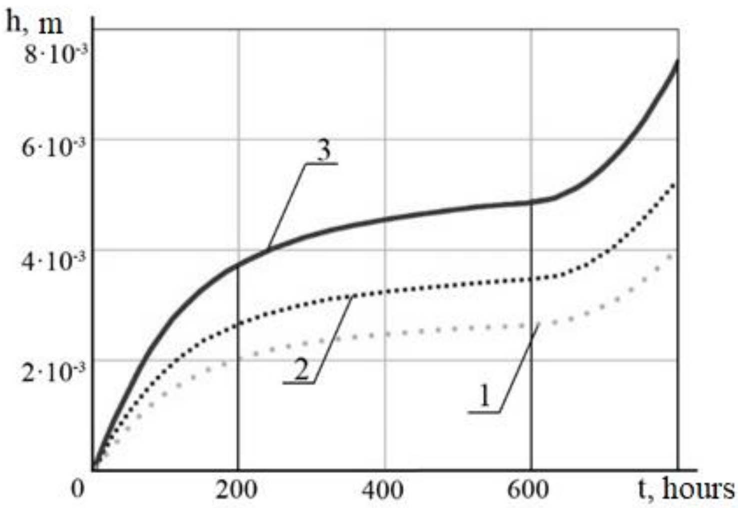

Fig. 2. Graph of wear rate *h* dependence on service life *t* for three different soil categories: 1 - soil category I, 2 - category II, 3 - category III

In equation (1), the first factor, which relates to the probability of blade failure-free operation and depends on the maximum load, was transformed as follows:

$$P(P_{dyn}) = 1 - \frac{1}{2\pi S_x \sigma_v} \int_0^{v_x} \int_0^{R_x} e^{-\left[\frac{(P-\bar{P})^2}{2S_x^2} + \frac{v^2}{2\sigma_v^2}\right]} dPdv, \quad (3)$$

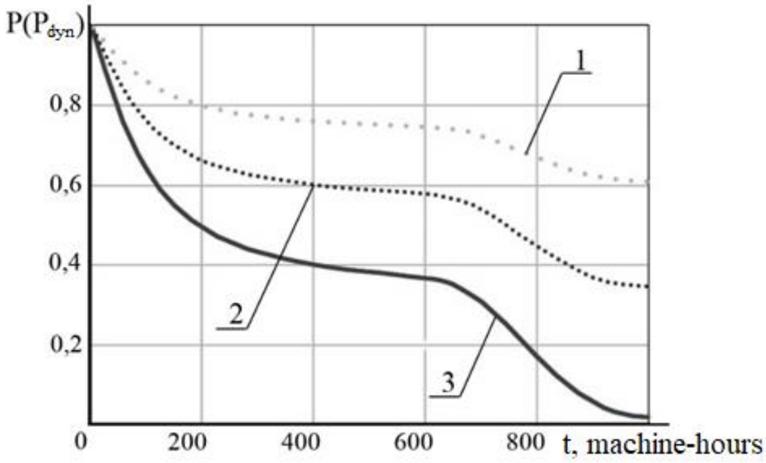

Fig. 3. категорія Graph of changes in the probability of failure-free operation of a bulldozer blade $P(P_{dyn})$ with the time of its operation in an abrasive environment t, h: 1 - I category of soil, 2 - II category, 3 - III category

Fig. 3 shows the dependence of the probability of bulldozer blade failure-free operation $P(P_{dyn})$ on the time of its operation in an abrasive environment, obtained by applying a normal distribution (3).

The declining characteristic of the graphs in Fig. 3 indicates a decrease in the probability of blade failure-free operation $P(P_{dyn})$ during the operation of the bulldozer working equipment.

As a result of approximating the dependence of the probability $P(P_{dyn})$on the blade's operating time in the abrasive environment t (Fig. 3), the following dependence was obtained

$$P(P_{dyn}) = 1 - 0.02 \cdot t^{1/z}, \tag{4}$$

where z = 2,4; 2,13; 2 – or soil categories I, II and III, respectively.

The proposed mathematical model of the total probability (1) allows us to obtain a theoretical description of the change in the probability of failure-free operation of the bulldozer working equipment in the process of performing work operations and describe the change in the service life of the bulldozer blade [8]. Based on the assumptions made, as mentioned above, it is suggested that we consider the probability of failure-free operation as a multiplicative probability function, each argument of which depends on the argument of another probability. In this case, the total probability of failure-free operation of the bulldozer blade will equal to:

$$P_{\Sigma} = P(P_{dyn})\left\{1 - \frac{1}{2}\left[\Phi\left[\frac{P_{-1}^{\max} - m(P_{-1})}{\sqrt{2D(P_{-1})}}\right] - \Phi\left[\frac{P_{-1}^{\min} - m(P_{-1})}{\sqrt{2D(P_{-1})}}\right]\right]\right\}\left\{\Phi\left[\frac{\frac{I_{ex}}{T^{\beta}} - m(a_u)}{\sqrt{D(a_u)}}\right]\right\}, \tag{5}$$

where $\Phi(x) = \frac{1}{\sqrt{2\pi}}\int_0^x e^{-\frac{t^2}{2}}dt$ – the Laplace transform,

$P_{-1} = P_{0-1} - R_x$;

P_{0-1} – the load-bearing capacity at fatigue load;

R_x – the applied load on the blade edge;

$m(P_{-1})$ – mathematical expectation (average value) of the limit of the difference between the load-bearing capacity of the bulldozer blade and the maximum load;

$D(P_{-1})$ – standard deviation of the limit of difference between load-bearing capacity and maximum load;

In the dependence $h(t)=a_u t^{\beta} + b_u$, we will consider the case of the extreme wear. In order to do this, we substitute the value of the extreme wear I_{ex} into the wear formula instead of $h(t)$ and solve the resulting equation for $t=T$ with $b_u = 0$. Then the blade service life will be as follows:

$$T = \sqrt[\beta]{\frac{I_{ex}}{a_u}}, \tag{6}$$

where I_{ex} – the extreme blade wear.

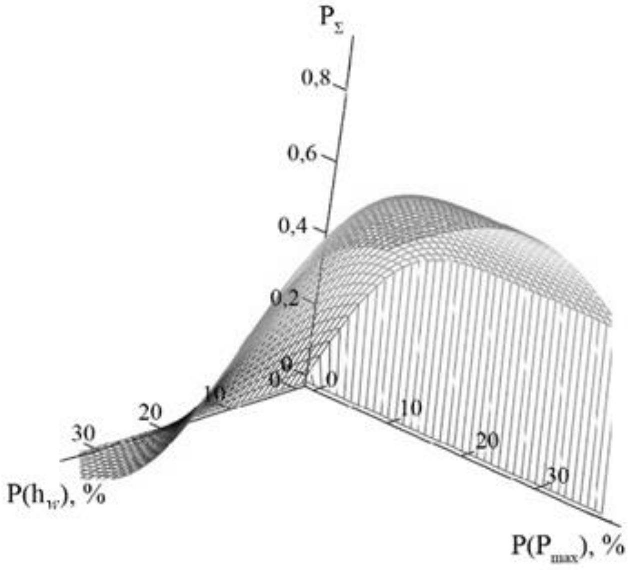

Fig. 4. Dependence of the change in the total probability of failure-free operation P_{Σ} on $P(P_{max})$ and $P(h_w)$

Fig. 4 shows the graph-surface $P_{\Sigma}=f(P(P_{max}), P(h_w))$, built using the dependence (1).

Approximating the dependence of the total probability of failure-free operation of the working equipment P_{Σ} on the probabilities $P(P_{max})$ and $P(h_w)$, we obtained:

$$P_{\Sigma} = 0.2 + 1.08P(P_{\max}) + 0.24P(h_w) - 0.13P(P_{\max})^2 - 0.08P(h_w)^2 + 0.846P(P_{\max})P(h_w). \quad (7)$$

Hence, the dependence of the probability of the blade failure-free operation was obtained, which includes wear parameters, dynamic and alternating load (Fig. 4). It should also be noted that the regression equation $P_{\Sigma}=f(P(P_{max}), P(h_w))$ is valid only within the limits of the experimental data, in particular the wear value, on the basis of which they were obtained [9]. If the values go beyond the experimental data, then the prediction of the probability of the blade failure-free operation can be obtained with significant errors. To extend the usage scope of the equations, they should be built based on the data regarding several or all modern models of objects of the same functional purpose.

Knowing the total probability of failure-free operation, we can determine the service life of the bulldozer blade. For this purpose, we need to solve equation (5) with respect to the value of T.

The Laplace transform is calculated only with the help of a special table. Therefore, equation (5) cannot be solved analytically. Thus, using MATLAB erf(x) operators, we will solve this equation numerically to find the total probability.

Taking into account the nonlinearity of the change in the blade wear value with the operating time $h_w=f(t)$ in an abrasive environment during work operations (Fig. 2), we find the service life of the bulldozer blade as the function of $T=f(t)$ (Fig. 5) for three categories of soil.

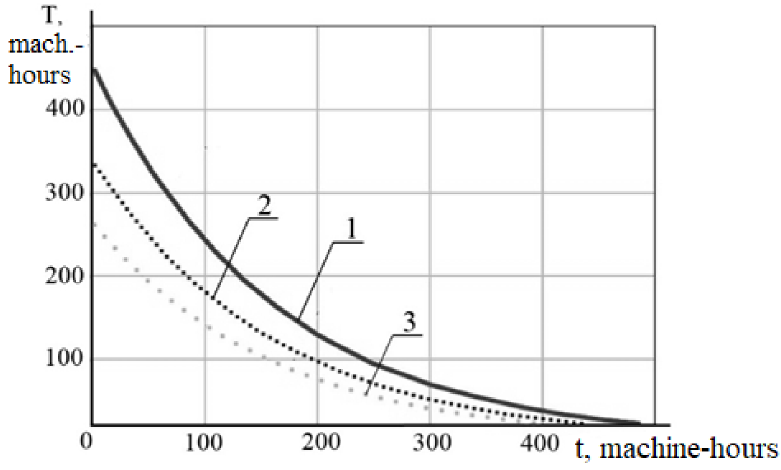

Fig 5. Dependence of the blade service life T on the time of its operation in an abrasive environment t: 1 - category I soil, 2 - category II, 3 - category III

The graphs in Fig. 5 show that the lower the soil category is, the higher the blade service life in this soil.

Approximating the dependence of the blade service life on the time of its operation in an abrasive environment, we obtain the following exponential dependence:

$$T(t) = x \cdot \mathrm{e}^{-\frac{t}{160}}, \tag{7}$$

Where the coefficient x=447; 340; 260 – for soil categories I, II and III, respectively.

The obtained equation does not contradict the class of solutions of the multiplicative equation (5) for the total probability of the blade failure-free operation of the bulldozer's WB.

Conclusions

1. On the basis of the multiplicative formula for the total probability of blade failure-free operation, an integral equation was obtained. It allows us measure the blade service life at any time before the start of a bulldozer operation.

2. The proposed mathematical model of the total probability allows obtaining a theoretical description of changes in the probability of failure-free operation of a bulldozer working equipment in the process of performing work operations, as well as changing in the service life of the bulldozer blade, and taking into account the properties of the material from which bulldozer blades are made.

3. The regularity of changes in the service life, due to bulldozer blade wear, is exponential.

4. The higher the soil category is, the more the wear is, therefore the service life of the bulldozer's working body is shorter.

5. The service life of a bulldozer cutting element can be estimated by its wear, structural features of the material, geometric parameters (thickness in particular), and machine operating modes.

References

1. Hustov Yu.I. Increase of wear resistance of working bodies and paring of construction machines. Mechanisation of construction.. 1996. №5. P. 15–16

2. Kravchenko I.N., Gladkov V.Y., Kartsev S.V., Trostyn V.P. Wear-resistant materials for restoration of working bodies parts of construction and road machines. Construction and road machinery. 2004. №5. P. 32–34.

3. Volkov D.P., Nikolaev S.N., Marchenko Y.A. Reliability of rotary trench excavators. M.: Mechanical engineering, 1972. 270 p.

4. Reish A.K. Increase of wear resistance of construction and road machinery. M.: Mechanical engineering, 1986. 184 p.

5. Anilovych V. Ya., Hrynchenko A.S., Lytvynenko V.L. Machine reliability in problems and examples. Kh.: Oko, 2001. 318 p.

6. Volkov D.P., Nikolaev S.N. Reliability of construction machinery and equipment. M.: Higher school, 1979. 400 p.

7. Ventsel Ye.S., Shchukin A.V. Wear resistance increase of working bodies of earth-moving machines. Kharkiv, 2015. 106 p.

8. Ye. Ventsel, O. Orel, O. Shchukin, N. Saienko, A. Kravets', Dependence of Wear Intensity on Parameters of Tribo Units, Tribology in Industry, Vol. 40, No. 2, pp. 195-202, 2018, DOI: 10.24874/ti.2018.40.02.03

9. Ventsel Ye.S., Orel O.V., Shchukin O.V. Improving the quality of lubricants, fuels and machine friction units. Kh.: IE Brovin O.V., 2017. 264 p.

Щукін О.В., Пруднікова А.О. Дослідження закономірності впливу зносу на ресурс різальних елементів робочих органів бульдозерів

Розроблено математичну модель, що описує закономірності зносу ножа і враховує вплив різних режимів експлуатації бульдозера при роботі його з різними ґрунтами з різним ступенем абразивності. При обчисленні ймовірності безвідмовної роботи різальних елементів (ножів) бульдозера, що залежить від максимального навантаження, встановлено, що ймовірність безвідмовної роботи при напрацюванні 600 маш.-годин становить: 0,7...0,75 – на І категорії ґрунту; 0,5...0,55 – на ІІ категорії ґрунту; 0,3...0,35 - на ІІІ категорії ґрунту. Порівняння ймовірностей безвідмовної роботи дало змогу встановити, що при підвищенні щільності ґрунту ймовірність безвідмовної роботи знижується на 30–40%, що дозволяє судити про значний вплив густини ґрунту на надійність робочого обладнання бульдозера. Крім того, розроблена математична модель сумарної ймовірності дозволяє отримати теоретичний опис зміни ймовірності безвідмовної роботи робочого обладнання бульдозера в процесі виконання робочих операцій, зміна ресурсу роботи ножа бульдозера і враховувати властивості матеріалу, з якого виготовляються ножі бульдозера. Ресурс ріжучого елемента бульдозера може бути оцінений, виходячи з його зносу, з урахуванням конструктивних особливостей матеріалу, геометричних параметрів (зокрема, товщини), режимів роботи машини. Встановлено, що закономірність зміни ресурсу від зносу ножа бульдозера носить експоненційний характер. Чим вище категорія ґрунту, тим знос, а отже і ресурс робочого органу бульдозера, менше. Отримано залежність зміни ресурсу ножа від часу його контакту з ґрунтами трьох категорій. Таким чином, максимальне значення ресурсу ножа на початку експлуатації на різних категоріях ґрунту: 450 маш.-годин – на І категорії ґрунту; 350 маш.-годин – на ІІ категорії ґрунту; 280 маш.-годин – на ІІІ категорії ґрунту.

Ключові слова бульдозер, ніж, ресурс, безвідмовна робота, знос, робоче обладнання, категорія ґрунту.