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Mathematical Modeling of the Wear of Cutting Elements on Quarry Excavators

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ABSTRACT: The use of hydraulic excavators in open pits has a high force effect on the teeth of the bucket, reduces the operating cycle compared to mechanical excavators by 15-18%, which in turn increases operational efficiency by 30-35%. The article also gives the factors that have a significant influence on tooth wear. After research and analysis, mathematical models were built and methods were determined to determine the wear rate of the teeth. This research is aimed at increasing the service life of replacement teeth, which will lead to a rapid reduction in the overall service life of the machine, since the lack of efficient use of earthmoving equipment is associated with significant wear of the working tools.

The essence of the numerical method is that knowing the profile coordinates of the i-st state and the direction of the wear vector for one step in the j-point the coordinates of the tooth profile for the i+1-st state are determined. The transition from one state to another is carried out discontinuously on the basis of the laws of of abrasion on the abrasive medium, which is a determined experimentally or theoretically-analytically determined path.

KEY WORDS: excavator bucket teeth, wear, friction angle, melting, cutting resistance, mathematical modeling, determine, coordinates, material, temperature, mining, deformed, abrasive

I. INTRODUCNION

During the start-up phase, the quality, durability and efficiency of single-bucket excavators need to be improved to increase the rate of operation. Over 80% of these excavators failures are caused by tooth wear, so it's important to improve the wear resistance of the of machines, which directly interact with the environment, by calculation and calculation [1]. Teeth are the main cutting tool of excavator buckets, in which the initial sharpening angle of the tooth increases significantly in the course of operation the initial angle of sharpening of the tooth and reduction of the working length, which to a large extent depends on the quality of the working length depends on the quality and type of material processed and the characteristics of the ground that is to be excavated material.

The excavator bucket teeth absorb significant mechanical, dynamic and abrasive loads during operation.

They are very prone to blunting when working in rocky or coarse-grained soils and when working in frozen ground. Experience has shown that under these conditions the tooth wears out in 10-12 days [2].

If an excavator tool is not replaced in a timely manner, more parts will need to be replaced than could be avoided with a timely diagnosis. Working with worn tines reduces productivity, increases wear and tear on the machine and causes additional costs.

Bucket tooth abrasion is an abrasive abrasion (in terms of exposure to soils) formed by the mechanical action of abrasive particles. Its peculiarity is that it is dominated by destruction resulting from the separation of microscopic volumes of metal by soil particles, which penetrate the cutting tool because of their high hardness.

The main cause of abrasive wear is the repeated plastic deformation of the same metal parts, causing their fatigue failure and the separation of metal particles from the surface layer. To a large extent the magnitude of wear depends on the abrasive pressure exerted on the surface to be abraded. Increasing stress provokes an increase in wear, as the penetration depth of active abrasive particles that leave scratches on the friction surface, and the number of particles in contact with this surface increases. particles in contact with the friction surface increases. It has also been shown that a reduction in temperature from + 20˚C to - 10˚C leads to 1,5...2 times increase of wear rate. 1.5...2 times, and when the temperature drops further down to -40˚C, it increases by 2.5...3 times [3].

The term 'tooth wear' refers to the process of breaking down the material of the excavator bucket teeth, which is caused by interaction with abrasive particles and occurs at varying intensities. As the teeth interact with the particles, scratches and chips form, resulting in the gradual separation of microscopic volumes of metal.

An increase in the degree of wear leads to a change in the optimum geometric parameters of bucket teeth. During operation, predicting changes in tooth hardness allows the degree of wear to be planned and, as a consequence, replacement times to be scheduled. This increases operating efficiency and reduces replacement costs for the working equipment depending on the category of soils to be excavated.

Optimizing the design of work equipment and work tools that interact with the work environment is an important trend in the development of earthmoving machinery. Improvements in the design of buckets operating on the mechanical destruction of soil have made it possible to reduce the energy intensity of work processes by 20-25% in the last 30-40 years. Energy intensity of the processes by 20-25% and a 15-40% increase in productivity machines, to increase the durability of teeth and buckets and develop cost-effective technologies for of their repair and restoration of workability [4].

The following factors influence the wear of excavator bucket teeth :

- the structure and surface properties of the metal layer which interacts with in contact with the medium (chemical composition, heat treatment and forming methods) the chemical composition of the metal layer that interacts with the medium (chemical composition, heat treatment methods, steel formability);

- Properties of the medium (hardness, strength, particle size, degree of homogeneity) Properties of the medium (hardness, strength, particle size, degree of homogeneity)

- The load on the tooth on the ground side;

- Ground temperature;

- Ground conditions.

II. SIGNIFICANCE OF THE SYSTEM

The paper mainly focuses on how machine learning techniques in Data mining can be applied to predict spam risk factors in the data used. Section II presents a literature review and Section III explains the methods, Section IV discusses the experimental results of the study and selection V Conclusion.

III. MATERIALS AND METHODS

To ensure self-sharpening of tillage tools the following relationship is used in [5]:

$$J = \frac{P^2[3\pi(HV) - 2P]}{2\pi(HV)^2 n_p \sqrt{\pi P(HV) - P^2}} \quad (1)$$

Here:
P - is the specific pressure on the tool, MPa;
n_p - number of cycles, resulting in failure of the deformed volume of the material;
HV – material micro – hardness, MPa.

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Taking the wear rate across the thickness of of the tillage tool is the same, i.e. $J_1 = J_2 = ... = J_n$, we get the expression

$$(HV)_i = f(P, J, n_p) \tag{2}$$

A method of manufacturing soil-cutting tools by by casting into foam polystyrene models, where the hardness surface hardness changes according to the given law, is considered in V.I. Zrulin [5].

The input data that characterizes the operating mode, P - cutting edge force and V_k - digging speed ground. Influence of temperature of environment and soil is neglected due to their small influence on the final result calculation.

Suppose that the force P' is directed along the horizontal the plane of the ground O_1 O_2. Then the force P acting on the tooth wedge and the resistance to its penetration is determined from figure 1.

$$P = P'\cos(90-\gamma) = P\sin\alpha \tag{3}$$

To describe the shape of the tooth during wear we use a power relationship of the form:

$$z = (c\rho + b)n \tag{4}$$

The equation coefficients for some tooth shapes are as follows: For the wedge c = 3.5; b = 0; n = 1, and for the blind tooth c = 1; b = 0.5; n = 1.5.

Measurements show that the cross-section of the tooth is elliptical in shape with dimensions:

$$a_j = 0,586\, z_j + 10$$
$$b_j = 0,182\, z_j + 3,2 \tag{5}$$

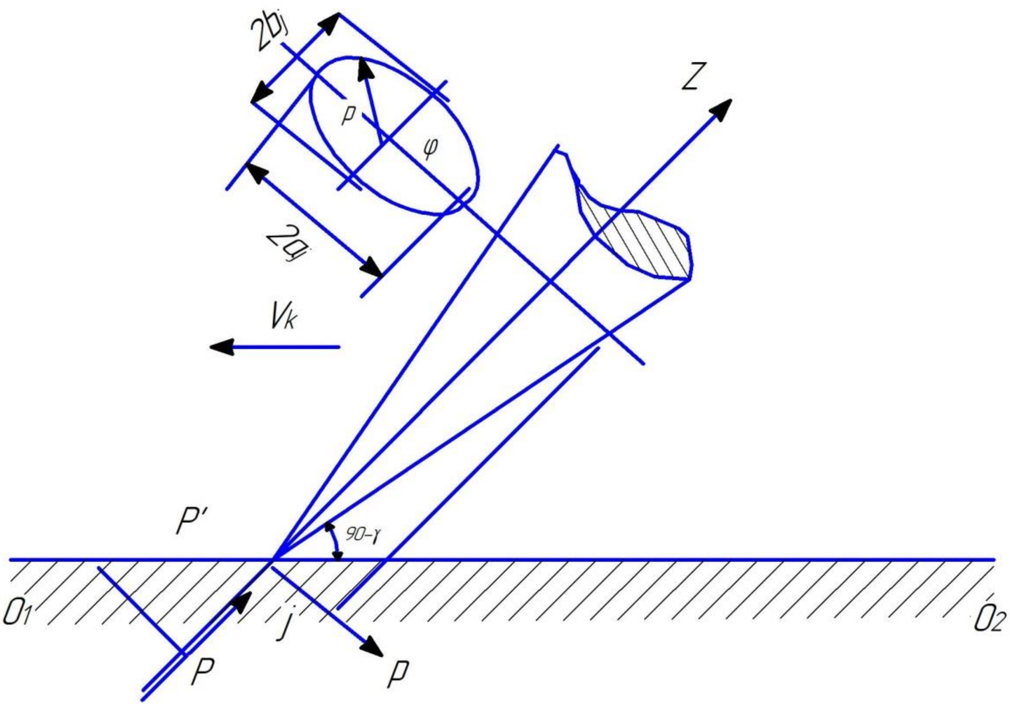

Figure 1. Coordinate system to describe the position and shape of the tillage tool

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To solve the problem of calculating the abrasion of the tillage tool in abrasive mass (soil), a mathematical apparatus of numerical methods was used. mathematical apparatus of numerical methods.

The initial tooth shape is described by discrete points on the surfaces. After a certain operation time t the tooth will have a different discrete state through which the friction surface friction surface during operation.

To determine the wear step we take a small value of of tooth wear Δh_j for small finite time t, when the tooth wear on each j-th element will be:

$$\Delta h_{ij} = J_{ij}\, V_к\, \Delta t \qquad (6)$$

Here:
Δh – ultimate low depreciation value, mm;
J – intensity wear rate of the surface layer material in the abrasive mass, mm;
$V_к$ – excavation speed, m/sec.

To solve the problem numerically, we divide the curve, describing the tooth shape into a number of segments at arbitrary interval $\Delta\rho$ with coordinates of the nodes at $\phi = 0$ we have $\rho_j = j\Delta\rho$

$$Zj = (c\, \rho i + b)n \qquad (7)$$

Here:
ρ, z are coordinates;
i - is the order number of the state;
j - is the number of node point.

In a cylindrical coordinate system, the cross-sectional radius of the tooth is described by the equation:

$$\rho_j = \frac{b_j}{Sin^2\varphi + \frac{b_j^2}{a_j^2} Cos^2\varphi} \qquad (8)$$

Here:
a_j, b_j – are the radii of the tooth section at height z.

Given that the wear vector is normal to the of the tooth surface, we find the value of the specific load at the nodal points:

$$Q_{ij} = P/A_{ai} \qquad (9)$$

Here:
A_{ai} – nominal friction surface, mm^2.

V. EXPERIMENTAL RESULTS

It is now necessary to determine the load distribution over the friction surface, which depends on the shape of the tooth.

To determine the coordinates of an arbitrary point M in the following condition, make the equations (see fig. 2).

$$tg\alpha = \frac{z_{ij}}{\rho_i};$$
$$z_{i+1.j} = z_{ij} + \Delta z;$$
$$\Delta z = \Delta h_{ij} Sin\left(\frac{\pi}{2} - \alpha\right);$$
$$z_{ij} = \rho_j tg\alpha;$$

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$$z_{i+1.j} = \rho_j tg\alpha + \Delta h_{ij} Sin\left(\frac{\pi}{2} - \alpha\right) \qquad (10)$$

The sum of the projections of the elementary loads on the z-axis equals load per tooth:

$$p = \pi a_i^2 \sum_1^M Cos\left(arctg\frac{z_{ij}}{\rho_j}\right) q_{ij} \qquad (11)$$

Here:
a – is the radius of the contact area of the soil particles with the surface of the tillage tool, mm.

Where from

$$q_{ij} = \frac{P}{\pi a_i^2 \sum_1^M Cos\left(arctg\frac{z_{ij}}{\rho_j}\right)} \qquad (12)$$

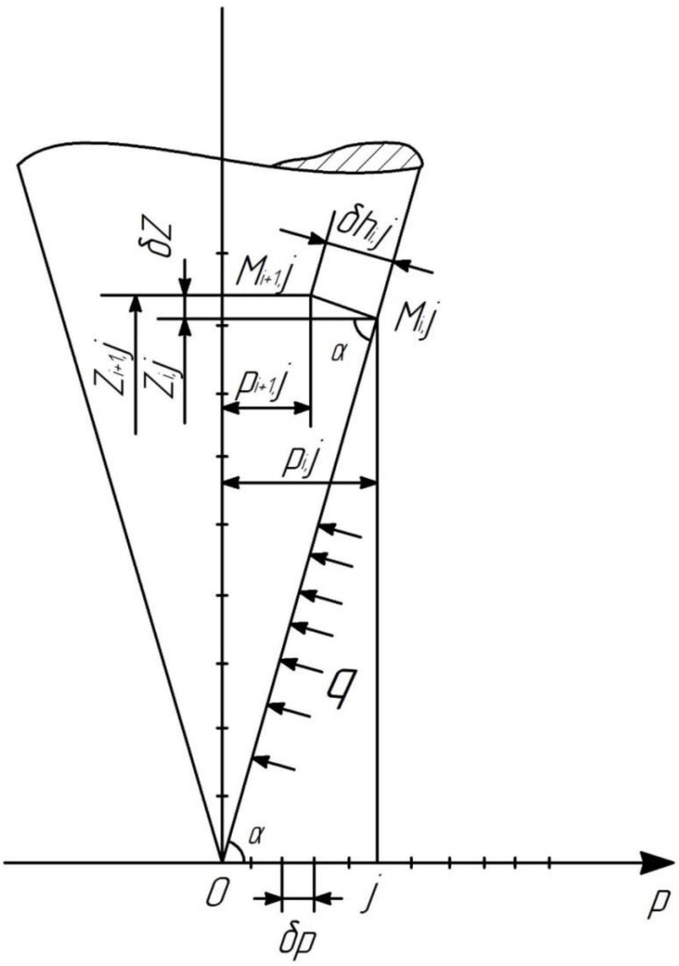

Figure 2. Schematic of tooth shape change during wear

Abrasive penetration depth in relation to load:

$$h = \frac{qF}{\pi d\ HB} = \frac{qa^2}{d\ HB} \qquad (13)$$

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Here:
HB – is the hardness of the tooth material;
d – is the average size of abrasive;
q – specific pressure;
F – contact surface area of the abrasive with the surface, $F = \pi a^2$.

Determine the deformed volume of the material by taking it equal to the embedded part of the abrasive in the form of a globular segment:

$$V = h(R - \frac{h}{3})n_a \quad (14)$$

Then

$$J = \frac{2h^2\left(R - \frac{h}{3}\right)n_a}{A_a \cdot a \cdot n_p} \quad (15)$$

Here:
a – radius of the abrasive contact patch with the surface;
n_p – is the number of cycles resulting in failure of the deformed volume of the deformed material by elastic and plastic interaction;
n_a – is the number of abrasive particles participating in abrasion.

The number of abrasive particles interacting with the work surface The number of abrasive particles interacting with the tooth surface is determined by the formula [6].

$$n_a = \frac{4A_a K_T}{\pi d^2 \sqrt[3]{\beta^2}} \quad (16)$$

Here:
β - soil density;
K_T - coefficient taking into account the correlation between the hardness of the abrasive and the is a coefficient that takes into account the correlation between the abrasive hardness and the abrasive material.

IV. CONCLUSION

The essence of the numerical method is that knowing the profile coordinates of the i-st state and the direction of the wear vector for one step in the j-point the coordinates of the tooth profile for the i+1-st state are determined. The transition from one state to another is carried out discontinuously on the basis of the laws of of abrasion on the abrasive medium, which is determined experimentally or theoretically-analytically determined paths.

The proposed calculation method has the following possibilities:

- The accuracy of the solution can be increased by a higher approximation of the transition from one state to another;
- In the program it is possible to use known solutions of similar problems, for example, a subprogram of calculation of friction units of sliding on abrasive wear;
- The speed of the computer ensures that several design variants can be calculated and the optimum design in terms of wear resistance can be selected.

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