The methods for determining the bucket parameters of a bulldozer-loader with transforming working equipment

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Abstract. Problem urgency. To improve the efficiency of road construction machines, especially in high altitude conditions, has been proposed a new design of a bulldozer-loader with transforming working equipment.
Purpose. Methodology development to determine the mass of proposed working body, i.e. the mass of bucket, excluding the mass of material that may be in the bucket.
Methods. Analyzed one of the main elements of the working body - the bucket. Further, using the formulas for determining the volume, we encountered that the lateral surface has a complex configuration, i.e. there are no clearly defined parameters like length and width.
Results. Obtained the dependence (mathematical model) for determining the mass of the bucket, which is easily used in the process of automatic calculation. As a result, reflected the main parameters, that influence to the indicators of reliability, durability of the metal structure and increase its operational properties and productivity.
Conclusions. According of dependence, by varying the parameters, it is possible to easily optimize the bucket volume without changing other parameters. Also, substituting the values into the dependence, it is possible to optimize the lifting capacity, productivity and other necessary parameters for the design of the working body and the base machine.

1 Introduction

When compiling and solving dynamic problems, from the point of simplifying the design schemes and to take into account the dynamic parameters of all available links, some of the given dynamic parameters (masses of all links of the working equipment) are introduced into the calculation. Therefore, defining them separately with mathematical expressions for the purpose of their further input to the main dependencies (mathematical models) contributes to an increase in the efficiency and accuracy of the calculation using a program with certain algorithms. According to the above, when analyzing and determining the values of the acting dynamic loads on the metal structures of the working equipment of machines and mechanisms, in particular during the operation of a bulldozer-loader with transforming

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working equipment, it is necessary to take into account the operating conditions. In this case, the operating conditions include the following, for example, the operating mode of the bulldozer-loader in the loader mode, because the proposed design can operate in the mode as the considered mode, the loader mode, and after transformation, in the bulldozer mode (Fig. 1) [1, 2, 3], in which the bucket acts as a support mechanism that holds the blade in the desired position in space with the creation of conditions for the moldboard working body, adjusting the cutting angle to ensure the rigidity of the moldboard surface, necessary in the mode of operation as a bulldozer, and the bucket is also the basic mechanism for strengthening the moldboard, through cylindrical hinges to the transforming working equipment. In addition, the operating conditions include the degree of filling of the bucket working body when operating as a loader.

2 Purpose

In this case, we will consider when the bulldozer-loader operates in the loader mode, i.e. the front part of the bucket is open completely (Fig. 1, a) [4, 5]. Here, the dump by turning around the cylindrical hinge joints, by means of hydraulic cylinders located on the end parts of the bucket and chain drives with sprockets, setting them in motion, i.e. by rotating the sprockets by clockwise, the blade is placed on the upper part of the bucket (Fig. 1, c) [3, 8].

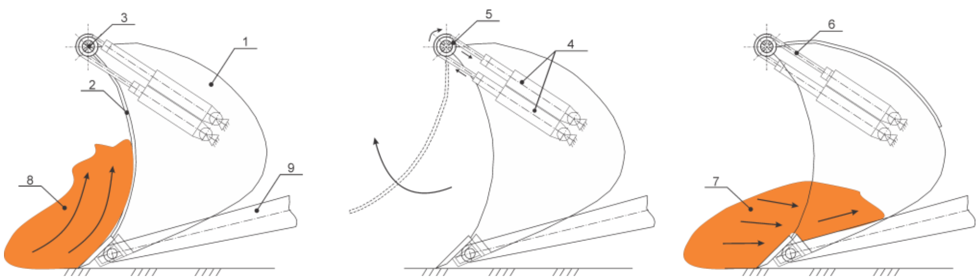


Fig. 1. Bulldozer-loader with transforming working equipment (drives and bucket control mechanisms are not shown): a) working process in bulldozer mode, b) transformation process, c) working process in loader mode, 1 - bucket; 2 - blade; 3 - cylindrical hinges; 4 - hydraulic cylinders; 5 - drive sprocket; 6 - drive chain; 7 - free-flowing medium (material); 8 - cut soil.

The purpose of this paper is to determine the masses of the working body, i.e. the mass of the bucket, at the beginning without taking into account the masses of the material in the bucket and without taking into account the masses of the moldboard working body (determined separately, will be summed as a separate mass). At the same time, it should be noted that the mass of the bucket with a load with a nominal volume will be considered, i.e. when the maximum value of the bucket filling factor ($Kn=0.2$) is taken into account, also with the volume of the bucket, when the bucket is filled to the edge of the front-end parts ($Kn=0$, without a slide) and the mass of an empty bucket with a certain volume, the so-called with strictly limited geometric dimensions.

3 Methods

Design analysis of working bodies bucket showed that the design of the bucket depends on their specified volumes, on their purpose, as well as on the conditions of attachment to the base machines. For example, the design of these parts, the design of the side (front-end) parts, and also the presence of rear and other visors depends on the volume of the bucket.

Along with the analysis of the design of the bucket working bodies, the analysis of the design of the moldboard working bodies [1, 2, 7, 8] was carried out in order to match the main parameters to each other, for example, the width of the blade to the width of the loader bucket, as well as the height of the blade to the height of the front bucket through which the masses are set into the bucket.

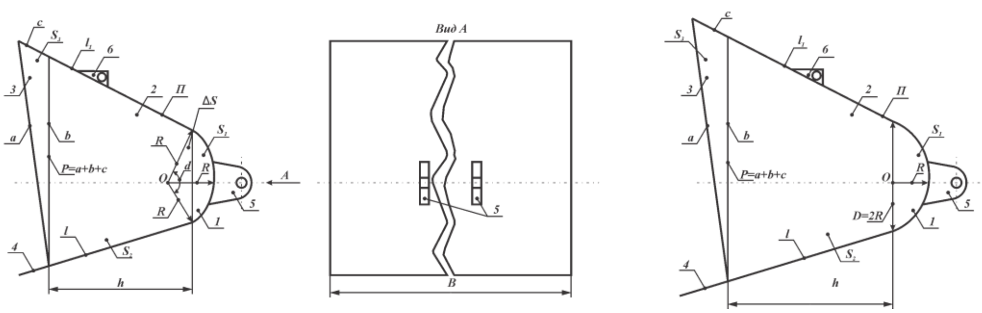
The results of the analysis showed that a bucket with a nominal volume (*Vnom*) at $Kn = 0.1 \div 0.3$; $Vnom \approx 1.5\ m^3$, bucket width *B* is $V \approx 2.0\text{-}2.3\ m$, and with a nominal bucket volume $Vnom \approx 1.8 \div 3.0\ m^3$, bucket width *B* is 2.5-3.0 m.

It is known that the volume of bodies is determined by multiplying the numerical values of three dimensions, for example, the base area is multiplied by the height, or:

$$V = a \cdot b \cdot h \tag{1}$$

where, *a* - length (first dimension); *b* - width (second dimension); *h* - height.

In turn, each of these dimensions, depending on the degree of complexity, in some cases are determined by a separate dependence. An illustrative example is the method for determining the volume of a loader bucket [9], in which the side (front-end) sides are presented as separate parts with complex configurations, i.e. there are no clearly defined parameters, such as length and width, and we take the bucket width *B* as the height parameter (Fig. 2).



a) b)

Fig. 2. Design of bucket working bodies: a) bucket with volume (V_H) less than 1.5 m^3; bucket with volume (V_H) up to 3.0 m^3; 1 - sidewall of the bottom of the bucket; 2 - main sidewall; 3 - sidewall of the rear visor; 4 - a knife with teeth; 5 - lugs for attachment to the loader arms; 6 - lugs for the bucket turning mechanism.

Analysis of the side (front-end) sides of the bucket showed that, depending on the volume of the bucket, as shown in Fig. 2, a, b, they differ, which can be described as follows:

First of all, it should be noted that in order to determine the area of the side surfaces, this surface is conditionally divided into separate areas, with the possibility of determining without any special difficulties, with the summation of the results obtained.

The side surface of the bottom part with bucket volumes ($Vnom \approx 1.5\ m^3$) represents the area of a circular segment that is not equal to a semicircle (Fig. 2,a) of which can be calculated by the formula according to Fig. 2,a

$$S_1 = \frac{\pi R^2}{360} \cdot \alpha - \Delta S \tag{2}$$

where, the first part of the formula $S_1 = \frac{\pi R^2}{360} \cdot \alpha$ is the area of the circular sector, R is the radius of the circle; α is the degree measure of the corresponding central angle; the second part ΔS is the triangle area with apex in the circle center and at the radius ends R, bounding the corresponding sector.

As shown in fig. 3, the side area (front-end faces) of the bucket is divided into separate sides as S_1, S_2 and S_3, and the above is the method for determining the side S_1.

According the above method, where with using formula (2) is calculated the area ΔS, which is limited by the area formed between the two radiuses R of the circular sector and the line, connecting the ends of the two generators of the radiuses R of the circular sector or, more correctly, by a straight line, limited by the circular segment. The purpose is to form the correct area S_2 and S_3, in which the areas (S_2 and S_3) are determined according the Fig. 2, using standard formulas, for example, for trapezoid S_2 and for triangle S_3.

ΔS, in which the sides are equal, i.e. isosceles triangle, angle α is the central angle of a circle with radius R. If the lengths of the sides and the angle α formed by the sides are equal to R, then the length of one side as b' can be determined by the cosine theorem

$$b' = \sqrt{2R^2(1 - cos\alpha)} \tag{3}$$

If the value of α (the central angle formed by a circle radius R) is not known, then the length of the side b' of the triangle $\Delta b' \cdot R \cdot R$ can be determined using the theorem "about the triangle middle line", which reads as follows - "The triangle middle line" is a segment connecting the midpoints of its two sides (Fig. 3),

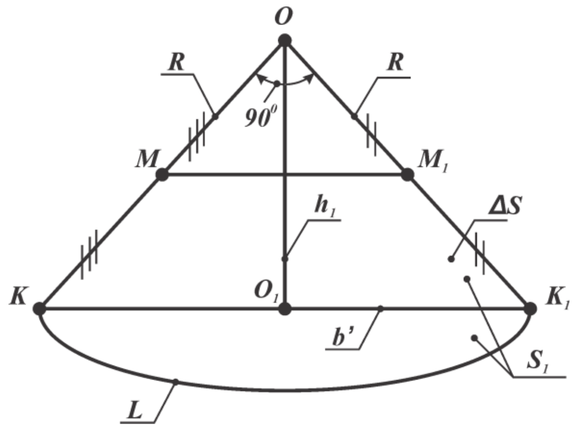


Fig. 3. Circular sector.

that is, we define points M and M_1 with a ruler (measuring device), then using the formula

$$MM_1 = \frac{1}{2}b' \qquad \rightarrow \qquad b' = 2MM_1 \tag{4}$$

$$\alpha = arccos\left(1 - \sqrt{\frac{b'}{2R}}\right) \tag{5}$$

The specified method for determining the triangle side refers to the graphic-analytical method. To determine the value of the unknown side of a triangle, with the known two sides, by the analytical method, for the purpose of calculating by a machine, i.e. with software with substitution of formulas for mathematical models, you can use the "proportional average" method (Fig. 4), which is explained by the fact that the number $x = \sqrt{ab}$ is the mean the average term of the proportion

$$a : x = x : b \tag{6}$$

Considering that in a right-angled triangle *ABC, AD* and *BD* is the projection of *AC* and *BC* onto the hypotenuse

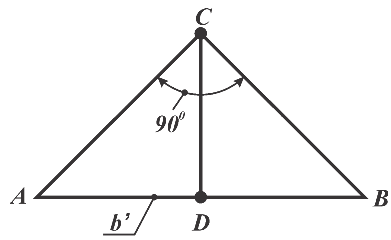


Fig. 4. "Proportional average" method for determining the triangle sides.

According to the above, the next equalities are true $AC = \sqrt{AB \cdot AD}$, $BC = \sqrt{AB \cdot BD}$, $CD = \sqrt{CD \cdot AD}$. In the case under consideration *AC*=*CB*=*R*. Then, we have

$$b' = R\sqrt{2} \tag{7}$$

As noted, to increase the efficiency of the machine calculation method, we analytically determine S_1, when *Vnom*<1,5 m^3.

If the three sides of the triangle *ΔS* are known, then the area is easily determined by the well-known formula

$$\Delta S = \frac{1}{2} b' h_1 \tag{8}$$

where, h_1 – the height of the triangle.

According to the conditions, the triangle RRb' is isosceles, then dropped from the vertex O to the base b' is the height h of the triangle, at the same time the side b' divides by two.

Then, according to the Pythagorean Theorem, property of an isosceles triangle the dependence (7) is transformed and we finally get

$$O_1K = \frac{R\sqrt{2}}{2} \tag{9}$$

Finally ΔS is equal

$$\Delta S = \frac{1}{2} b' \sqrt{\frac{R\left(2R - \sqrt{2}\right)}{2}} \tag{10}$$

(10) is substituted into (2) and we get

$$S_{1segment} = \frac{\pi R^2}{360} \cdot \alpha - \frac{1}{2} b' \sqrt{\frac{R\left(2R - \sqrt{2}\right)}{2}} \tag{11}$$

A platform (S_1) as shown in Fig. 2,b with a bucket volume *Vnom* up to 3 m^3, but more than 1.5 m^3 (3,0> *Vnom* >1,5), is represented as half a circle with a radius also equal to *R*, which is determined by the formula

$$S_{1segment} = \frac{\pi R^2}{2} \tag{12}$$

The area S_2 (Fig. 2, a, b) is determined by the trapezoid formula

$$S_{2trapezoid} = \left(\frac{b + b'}{2}\right) h = \left(\frac{b + 2R}{2}\right) h \tag{13}$$

where, b *and* b' - trapezoid base; h - height; *R* - circle radius of the bucket bottom sides.

The area S_3 (lateral sides) formed by the line *a, b* and *c* (Fig. 2, a, b) is determined using the Herron formula (ancient Greek scientist)

$$S_{3triangle} = \sqrt{P(P-a)(P-b)(P-c)} \tag{14}$$

where, *a, b, c* – sides of a triangle, *P* – its perimeter.

According to the conditions and the results of the analysis of the operating structures of the loader bucket, the parameter *b* (Fig. 2, a, b) is from 1.0 to 1.1 m, and the so-called "rear visor" *c* is approximately equal to 0.2-0.23 m, then the length *c* is determined by dependence $AC = \sqrt{AB \cdot AD}$, $BC = \sqrt{AB \cdot BD}$, $CD = \sqrt{CD \cdot AD}$.

4 Results

Finally, according of method for determining the areas S_1, S_2 and S_3, the basic formulas (dependencies) are derived. According to the above, the total lateral surface area is determined

$$S_{general} = S_{1segment} + S_{2trapezoid} + S_{3triangle}$$

or

$$S_{general} = \frac{\pi R^2}{360} \cdot \alpha - \frac{1}{2} b' \sqrt{\frac{R^3-\sqrt{R}}{R}} + \left(\frac{b+b'}{2}\right) h + \sqrt{P(P-a)(P-b)(P-c)} \quad (15)$$

Then, the volume of the bucket is determined by the dependence

$$\mathrm{V}_{bucket} = \left[\frac{\pi R^2}{360} \cdot \alpha - \frac{1}{2} b' \sqrt{\frac{R^3-\sqrt{R}}{R}} + \left(\frac{b+b'}{2}\right) h + \sqrt{P(P-a)(P-b)(P-c)}\right] B \quad (16)$$

If necessary, to determine the masses (m) of the loader bucket, we multiply the found surface areas by the thickness of the material from which the bucket sides are made separately.

Further, we multiply the obtained volumes by the density of the material ρ [kg/m^3], that is, the total volume of the side surfaces

$$V_{side\,surface} = 2S_{general}\delta x \left[\frac{\pi R^2}{360} \cdot \alpha - \frac{1}{2} b' \sqrt{\frac{R^3-\sqrt{R}}{R}} + \left(\frac{b+b'}{2}\right) h + \sqrt{P(P-a)(P-b)(P-c)}\right] \quad (17)$$

where, δ - material thickness (steel.45, GOST 1050-2013), δ = 10 mm = 0,01 m.

Side surface mass

$$m_{side\,surface} = V_{side\,surface} \cdot \rho \quad (18)$$

To determine the masses of the forming bucket, first by expanding the lateral surfaces of the forming parts along the perimeter, such as the upper, bottom, lower parts of the bucket, and multiplying by the width of the bucket B, we obtain the formative area

$$S_{formative} = P_{side\,surface} \cdot B \quad (19)$$

where, $P_{side\,surface}$ - lateral perimeter, B - bucket width.

The perimeter of the side surfaces consists of the following parts:

- the bucket bottom perimeter is defined as the arc length $KK_1=L$ (Fig.2, Fig.3)

$$L = \frac{\pi R}{180} \cdot \alpha \quad (20)$$

where, R - circle radius, α - degree measure of the central angle.

- the perimeter l_1 is determined by the Pythagorean Theorem through the height h_1 by the formula

$$l_1^2 = h^2 + \left(\frac{b-b'}{2}\right)^2 = \sqrt{h^2 + \left(\frac{b-b'}{2}\right)^2} \quad (21)$$

where, $\frac{b-b'}{2}$ - the difference between the parameters b and b', correspond to the two sides of a drawn perpendicular, at the same time is the height of the trapezoid h.

The sweep length is $P_{side\,surface} = L+2l_1+C$. By multiplying the bucket width B and density, we find the mass

$$V=(L+2l_1+C)\cdot\delta \quad (22)$$

After substituting the (20), (21) into (22), is determined the mass of the loader bucket

$$m = \left[\frac{\pi R}{180} \cdot \alpha + 2\sqrt{h^2 + \left(\frac{b-b'}{2}\right)^2} + c\right] \cdot \delta \cdot \rho \quad (23)$$

where, δ - material thickness (steel.45, GOST 1050-2013), δ = 10 mm = 0,01 m, ρ = 7500-7850 kg/m^3.

5 Conclusions

As practice shows, for a more accurate substantiation of the magnitude of the acting dynamic loads on the metal structures of the bulldozer-loader with the effective use of automatic calculation, it is necessary to derive and write the dependencies defining them. After processing the mathematical model, one can clearly see the main parameters that affect the reliability, durability of the metal structure, and also clearly see the main parameters that affect the increase in productivity and operational properties.

For example, dependence (7), by varying with the parameter b' with substituting into dependence (11) we can easily optimize the bucket volume, the lifting capacity, productivity and other parameters necessary for design without changing other parameters. The proposed design is operated in a bulldozer mode and after transformation - in a loader mode, and optimization of parameters for such operating modes is an urgent task.

As you can see, in the process of operation of a bulldozer-loader with a transforming working body, some masses create additional inert loads, and in some cases, these masses perform useful work as a mass for the effective introduction of a bucket into the mass in the loader operating mode.

Our goal is to establish the laws of the influence of the masses on the work process, by taking them into account with the definition of directions of action and their redistribution between the nodes of the structure.

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