UDC621.872 DOI: 10.30977/AT.2219-8342.2023.53.0.03

The method of determining the parameters of the soil prism formed in front of the dump during digging

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Abstract. Problem. *The studied dynamic process of digging, taking into account the variable total moving mass of wheeled ETM equipped with a dump, is not sufficient for the development of recommendations for selecting rational parameters for the performance of such a technological operation. The issue of determining and analyzing the parameters of the variable mass and volume of the material prism moved by the dumper has not been sufficiently investigated. There in no engineering technique that allows you to determine the parameters of the material prism that is gradually forming before dumping.* ***Methodology.*** *The measures are aimed at determining the parameters of the soil prism before the dump in the digging process using analytical dependencies.* ***Results.*** *For the processes of development and analysis of dynamic models of machines with a shovel working body for the stages of digging and transportation of material, it is necessary to take into account its mass in the form of mass attached to the mass of the machine itself.* ***Originality.*** *The obtained dependencies allow to take into account the variable mass of the attached material when performing the analysis of the bulldozer movement in the process of digging the environment being developed.* ***Practical value.*** *The obtained results can be recommended when studying the disciplines of industrial mechanical engineering.*

Keywords: *bulldozer, prism, dump, dynamic process, technological operation*

Introduction

Among machines for earthworks, experts single out earthmoving and transport machines (ETM) in a separate group. These machines include bulldozers, scrapers, motor graders and grader-elevators. Some researchers also include single-bucket front loaders in ETM. This division is due, first of all, to the peculiarities of technological operations. The driving force, which ensures the execution of a technological operation, is developed by the running equipment of such machines. This means that the operations of digging the soil, transporting it to the place of unloading and returning ETM back to the slaughterhouse are provided due to the driving force that is formed in the contact zone of the running equipment (tracks, wheels) with the supporting surface. At the same time, a significant part of the external supports (general working supports) is perceived by the working body. The ETM in the contact zone of the running equipment and the support surface is additionally affected by rolling resistance forces.

The operation of digging the developed environment with a dump working body is accompanied not only by the separation of shavings from the soil massif, but also by its successive accumulation in front of the dump in the form of a prism of material. Since the mass of the prism can be significant and comparable to the mass of the ETM itself, the operation of digging the developed environment can be considered from the point of view of the dynamics of solid bodies as a stage of the undetermined movement of the ETM. It should be especially taken into account that the volume, and therefore the mass, of the displaced material prism at this stage increases from zero to its limit value. This fact can affect the performance indicators of ETM. For example, for a bulldozer in the situation of moving mined material over short distances, the duration of the digging stage can occupy a significant part of the entire working cycle of the machine. Since not only the machine itself is moving, but also the variable mass of material attached to it, which is in the prism, it can be expected that the parameters of this dynamic process will also change.

In particular, the duration of the stage of digging the mined material may change. Failure to take into account this fact can lead to an incorrect assessment of the productivity of the ETM, and the lack of analytical dependencies that would take into account the variable mass of the material prism formed before the dump, will not allow to identify and analyze the dynamic characteristics of the stage of digging the material and develop measures to increase the productivity of the ETM.

Analysis of publications

In the works of K.O. Artemyeva, V.V. Nitschke, L.A. Clouds and other authors, when calculating the productivity of scrapers, it is recommended to take into account the variable mass of soil in the bucket of the machine during the digging operation [1-7]. The proposed analytical dependencies developed by the researchers take into account the decrease in the speed of the machine as the bucket is filled with mined material.

For machines equipped with a dump working body, calculations are usually performed only for situations of maximum load. The proposed approach is applied to tracked machines, since the slip coefficient of their running gear does not change significantly with the increase of external resistances and the increase of the total weight of the machine and the transported material. On the other hand, for wheeled ETM with a dump working body (wheeled bulldozers, motor graders), the change of these parameters has a significant effect on the real speed of ETM movement due to an increase in the slip coefficient, which is confirmed by the works of M.O. Ulyanova, P.I. Nikulin and their students. According to the conducted studies, the slip coefficient of the wheel ETM can be represented in the form of a polynomial equations of the fifth-sixth degree on the total resistances acting on the ETM.

$$\delta=\frac{\upsilon_m-\upsilon_l}{\upsilon_m}=A\frac{T}{R}+B\left(\frac{T}{R}\right)^m \qquad (1)$$

where δ – slip coefficient; υ_m – theoretical speed of movement of wheeled ETM; υ_l – actual speed of movement of the wheeled ETM; T is the traction force on the driving moving wheels. This effort in transient processes is equal to

$$T=\begin{cases}\Sigma W & \text{at} \quad \Sigma W < T_f \\ T_f & \text{at} \quad \Sigma W \geq T_f\end{cases} \qquad (2)$$

where ΣW – total supports acting on the machine during the digging operation of the material being developed; T_f – traction force under the conditions of traction of the running equipment with the support surface; R – support reaction on leading drivers; A, B are empirical coefficients.

Equation (2) is valid for energy-saturated machines.

The analysis of scientific and technical information dedicated to the study of the dynamics of the digging process, taking into account the variable total moving mass of wheeled ETM equipped with a dump, is not sufficient for the development of recommendations for the selection of rational parameters for the performance of such a technological operation. In addition, the issue of determining and analyzing the parameters of the variable mass and volume of the material prism moved by the dumper has not been sufficiently investigated.

This fact can be explained by the lack of an engineering technique that allows you to determine the parameters of the material prism before the dump, which is gradually formed.

Purpose and Tasks

The purpose of the proposed article is to develop a method for calculating the parameters of the material prism, which is formed in front of the dump working body during the technological operation of digging the developed environment.

Analysis of the parameters of the maximum mass of the material prism, which is formed before the dump of serial wheeled bulldozers

Within the framework of the conducted research, it was decided to estimate the expected values of the mass of the soil, which is moved by a bulldozer during technological operations. Caterpillar Inc.'s wheeled bulldozers were chosen as the research object. (see Fig. 1, 2) [8, 9]. During the analysis, the following aspects were taken into account:

– caterpillar Inc. supplies wheeled bulldozers with four different dump types: straight, spherical, hemispherical and coal (see Fig. 3) [8, 9];

– dumps are intended for various technological operations. A straight dumper performs standard bulldozer operations such as digging soil, processing bulk materials and moving soil, minerals and construction materials. Spherical scrapers, thanks to their design features, make it possible to form larger prisms of the processed material compared to straight scrapers. The company generally recommends using them to move heavy materials over long distances in the mining industry. Hemispherical dumps occupy an intermediate position between straight and spherical dumps. To work with light materials, for example, to move coal, the company recommends using special coal dumps, which allow forming a prism of material much larger than spherical dumps. A rational choice of dump type, taking into account the performed technological operation, allows to significantly increase the productivity of the bulldozer [8, 9];

The calculations take into account the maximum volume of the material prism formed in front of each type of dump. This volume is regulated by the Caterpillar company in its prospectuses for the corresponding machines [8, 9].

Fig. 1. Caterpillar Inc. wheeled bulldozer 824k

Fig. 2. Caterpillar Inc. wheeled bulldozer. 854k

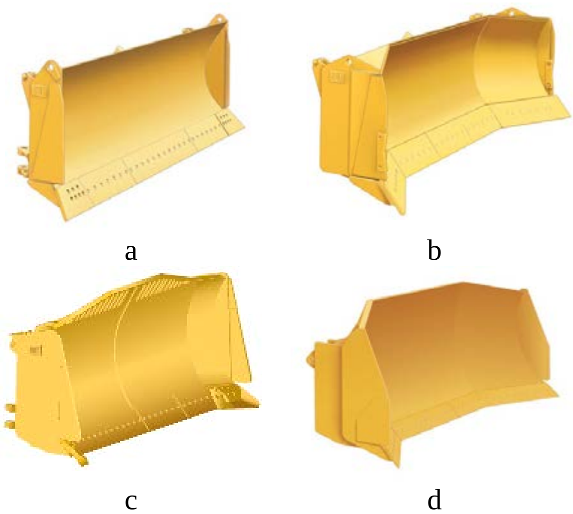

Fig. 3. Types of scrapers installed on Caterpillar Inc. wheeled bulldozers: a – straight scraper; b – spherical dump; c – hemispherical dump; d - coal dump

The results of the calculations are given in Table 1.

Table 1. The value of the mass of the soil (processed material) formed into a prism before the dump of the bulldozer

Brand bulldozer	N, kW	m_b, t	Dump type	V_{sl}, m^3	Material	δ_{sl}, t/m^3	k_p	m_g, t	$\frac{m_s}{m_b}$
824k	302	34	direct	5.0	difficult loam	1.95	1.26	7.74	0.228 (22.%)
			spherical	7.7	sand	1.7	1.15	11.38	0.335 (33.5%)
			hemispherical	7.7					
			coal	16.2	coal	0.8		12.96	0.38 (36%)
834k	370	47.75	direct	7.9	difficult loam	1.95	1.26	12,23	0.256 (25.6%)
			spherical	11.1	sand	1.7	1.15	16.4	0.344 (34.4%)
			hemispherical	10.1				14.9	0.313 (31.3%)
			coal	22.2	coal	0.8		17.76	0.372 (37.2%)
854k	607	101.72	hemispherical	25.4	sand	1.7	1.15	34,55	0.37 (37%)
			coal	44.7	coal	0.8		35,76	0.352 (35.2%)

The following letter designations are used in the table: N – nominal power of the bulldozer engine, kW; m_b – bulldozer mass, t; V_{sl} – the maximum volume of the material prism (according to the company), m^3; δ_{sl} – density of the material in its natural state, t/m^3; k_p – coefficient of loosening of the material; mg is the mass of the material in the prism, i.e.

The density of coal is indicated for the loosened state.

Analyzing the results of the performed calculations, it can be stated that the mass of material in a fully formed prism can be compared with the mass of the bulldozer itself and, depending on the type of dump and the characteristics of the environment being developed, can be from 23% to 38% of the mass of the machine itself. This fact can significantly affect the dynamic parameters of the bulldozer movement process.

Justification of the method of determining the parameters of the soil prism before the dump in the process of digging using analytical equations

As an object of research, we will choose a bulldozer with a non-rotating dump, which performs the operation of digging the soil. Since the volume of material in front of the bulldozer dump increases during the digging process, it is necessary to determine the equation of the mass of the cut material in the form of a function of the movement of the machine in order to compile a dynamic model of the movement of the machine. When deriving the equation, we consider that the tilt angle of the dump in the vertical direction is equal to zero, and the capture angle corresponds to 90˚. In general, the digging depth h can vary arbitrarily depending on the movement of the machine x (Fig. 4).

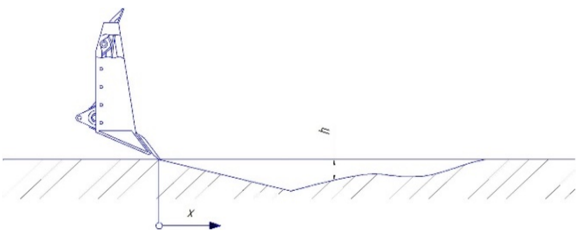

Fig. 4. Longitudinal section of the face for the operation of digging the working environment with a bulldozer dump

The volume of cut material from the main array is determined by the integral equation:

$$V_s = B\int_0^x h(x)dx\,, \qquad (3)$$

where B is the width of the chip of the cut material (the width of the knife system of the dump); $h(x)$ is the chip thickness of the cut material (cutting depth); x is the longitudinal displacement of the bulldozer.

It should be taken into account that in the process of cutting the material, its destruction occurs. This leads to an increase in its volume. This fact can be taken into account using the coefficient of loosening of the material k_p. The real volume of loosened material before the dump is determined by the formula

$$V_{sl} = k_p V_s = k_p B\int_0^x h(x)dx\,. \qquad (4)$$

In the process of moving a prism of material with a bulldozer blade along the support surface, part of the prism will move into the side rollers. This loss of material from the prism can be accounted for using a material loss factor k_n. Finally

$$V_{sl} = (1-k_n)k_p B\int_0^x h(x)dx\,. \qquad (5)$$

The coefficient of material loss is less than one and depends on the parameters of the support surface, material properties and the volume of the prism before the dump.

In the process of deriving the equation for determining the mass of the material before the bulldozer dump, it is necessary to take into account that the size of this prism is limited. The maximum possible volume of the prism depends on the geometric dimensions of the dump and the characteristics of the material. In work [1] experts recommend using the following equation (6).

$$V_{sl}^{\max} = \frac{BH^2}{2\,\mathrm{tg}\,\rho}k_f = \frac{BH^2}{2\,\mathrm{tg}\,\rho}\left(1-\frac{H}{B\,\mathrm{tg}\,\rho}\right). \qquad (6)$$

where H is the height of the dump; ρ – the angle of the natural slope of the material; k_f – prism shape factor.

Thus, the calculated volume of the material prism before the bulldozer dump is determined by the following conditions:

$$V_{sl} = \begin{cases} (1-k_n)k_p B\int_0^x h(x)dx; & \text{at } V_{sl} < V_{sl}^{\max} \\ V_{sl}^{\max}, & \text{at } V_{sl} \geq V_{sl}^{\max} \end{cases} \quad (7)$$

The mass of the material in the prism can be calculated as follows

$$m_s = V_{sl}\frac{\delta_s}{k_p}, \quad (8)$$

where δ_s - the density of the material in the natural massif.

When analyzing the dynamic characteristics of a bulldozer during technological operations, researchers often consider the machine as a dynamic single-mass system (Fig. 5) [10]. In the above diagram, the letter c indicates the elasticity coefficient of the working equipment and other systems of the bulldozer. Theoretically, in the process of moving the bulldozer, oscillating processes can occur inside the system itself, which will lead to the periodic disconnection and attachment of the mass of the material to the total mass of the machine.

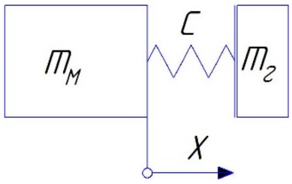

Fig. 5. Dynamic scheme of the bulldozer

If we take into account that during digging, the resistance forces on the dump increase and during forward movement of the machine, its acceleration is less than zero, and during oscillatory backward displacement - more than zero, then the total mass of the moving system can be determined from the equation (9).

$$\Sigma m = \begin{cases} m_m + m_s; & \text{at } \ddot{x} \leq 0 \\ m_m, & \text{at } \ddot{x} > 0 \end{cases} \quad (9)$$

where m_m – bulldozer mass; $\ddot{x}$ – acceleration of the center of mass of the bulldozer.

Conclusions

On the basis of the conducted research, the following conclusions can be drawn:

1. The mass of the soil (the material being developed), which is cut and moved by the bulldozer during the digging operation, can be compared with the mass of the machine itself and can reach 35% ... 38% of its mass.
2. The mass of the material in the prism in front of the bulldozer dump is variable and changes from 0 at the beginning of cutting to the maximum value that corresponds to the maximum permissible volume of the material prism.
3. In the process of developing and analyzing dynamic models of machines with a shovel working body for the stages of digging and transporting material, it is necessary to take into account its mass in the form of mass attached to the mass of the machine itself.
4. The proposed equation (7), (8) and (9) allow you to take into account the variable mass of the attached material when performing an analytical analysis of the bulldozer movement in the process of digging the environment being developed.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Метод визначення параметрів призми ґрунту, яка формується перед відвалом під час копання

Анотація. Проблема. *Досліджуваний динамічний процес копання з урахуванням змінної сумарної рухомої маси колісної ЗТМ, обладнаної відвалом, не є достатнім для розробки рекомендацій щодо вибору раціональних параметрів виконання такої технологічної операції. Недостатньо досліджено питання визначення та аналізу параметрів змінної за масою та обсягом переміщуваної відвалом призми матеріалу. Відсутність інженерної методики, яка дозволяє визначити параметри поступово формуючої перед відвалом призми матеріалу.* ***Мета.*** *Розробка методу розрахунку параметрів призми матеріалу, яка формується перед відвальним робочим органом під час виконання технологічної операції копання розроблюваного середовища.* ***Методологія.*** *Заходи спрямовані на визначення параметрів призми ґрунту перед відвалом у процесі копання за допомогою аналітичних залежностей.* ***Результати.*** *Для процесів розробки та аналізу динамічних моделей машин з відвальним робочим органом для етапів копання та транспортування матеріалу необхідно враховувати його масу у вигляді маси, приєднаної до маси самої машини.* ***Оригінальність.*** *Отримані залежності, що дозволяють врахувати змінну масу матеріалу, що приєднується, при проведенні аналітичного аналізу руху бульдозера в процесі копання середовища, що розробляється.* ***Практична цінність.*** *Отримані результати можна рекомендувати при вивченні дисциплін галузевого машинобудування.*

Ключові слова: *бульдозер, призма ґрунту, відвал, динамічний процес, технологічна операція*

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