УДК 624.132.1

Calculations difference of hight-speed working units depending on the kinematics of their working processes

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Received: 11.10.2021; Accepted: 23.11.2021
https://doi.org/10.32347/gbdmm2021.98.0101

Abstract. High-speed working units are very widely used in modern construction, in the destruction of durable materials and soils and more. When calculating the power and energy parameters of dynamic working units take into account changes in the nature of the interaction of the cutting element with the environment and the emergence and propagation of soil stresses from the action on the boundary of the array of the cutting element. This leads to the emergence of a stress-strain state in the soil mass, which has an oscillatory-wave character.

The nature of the stress-strain state is influenced by the state of the working environment and the speed of cutting (destruction) of the soil mass.

An unsolved problem in the dynamic destruction of soils is to take into account the kinematic features and technology of work with high-speed peripheral and front-end working units. The design parameters of these working units must take into account not only the dynamic parameters of the fracture process, but also the phenomenon of accumulation of fatigue deformations in the working environment.

Keywords: peripheral working unit, front-end first type working unit, front-end second type working unit, middle depth of cut, power cutting

INTRODUCTION

The stress-strain state of the medium in the cutting zone has an oscillatory-wave character, similar to that formed by shock-vibration destruction of soils, which is the most effective dynamic process of destruction of working media. This stress-strain state creates conditions for the accumulation of fatigue deformations in the material, so the tensile strength of the working medium is significantly reduced [1].

For effective low-energy destruction of materials, the design parameters of the working units must be determined from a systematic analysis of their working processes and meet the conditions of fatigue destruction of the material.

In addition, when destroyed, the soil is subject to loosening and compaction. This fact is taken into account by the flow coefficient, which determines the conditions of excavation of the soil from the face [2, 3]

The purpose of the work is to establish the laws of formation of the working process of dynamic destruction of soils, taking into account the kinematic features of the peripheral and end working units.

The aim of this study is to determine the power and energy parameters of the process of dynamic destruction of soils and kinematic and geometric parameters of peripheral and end working bodies of dynamic action.

In [4, 5], the solution of the problem of the relationship between the geometric, kinematic and force parameters of the working bodies of tillage machines under the conditions of high-speed (dynamic) work process of destruction of working environments.

PRESENTING MAIN MATERIAL

During the work process, the cutting elements of the working unit move relative to the working environment with speed V. This causes the working environment to be in a complex stress-strain state. Assuming that if the speed of the cutting element has become a force, the tangential average force acting on the cutting element without taking into account the conditions of soil vibration is determined by the formula

$$P_{av} = \frac{U k_d S}{2 V k_\alpha}, \qquad (1)$$

where
$U -$ speed of propagation of deformation waves in the working environment;
$k_d -$ specific resistance of the working environment to dynamic destruction;
$S -$ the area of contact of the cutting element with the working environment;
$V -$ speed of interaction of cutting elements with the working environment (cutting speed);
$k_\alpha -$ coefficient taking into account the cutting angle.

The velocity of propagation of deformation waves in the working medium is found from the expression

$$U = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}}, \qquad (2)$$

where
$E -$ dynamic modulus of elasticity of the working environment;
$\rho -$ the density of the working environment;
$\mu -$ Poisson's ratio.

The specific resistance of the working environment to dynamic failure is as follows

$$k_d = \rho V^2 + \sigma\varepsilon, \qquad (3)$$

where
$\sigma -$ dynamic limit of the strength of the working environment to dynamic failure;
$\varepsilon -$ ultimate dynamic relative deformation.

The geometric parameters of the working process (such as the depth of cut and the area of contact of the cutting elements with the working environment) are determined differently depending on the technology of the working unit. Based on this, we can distinguish two main types of working units: peripheral (Fig. 1) and front-end (Fig. 2 and Fig. 3). Front-end working units, in turn, are divided into front-end first type working unit of the (Fig. 2) and front-end second type working unit (Fig. 3).

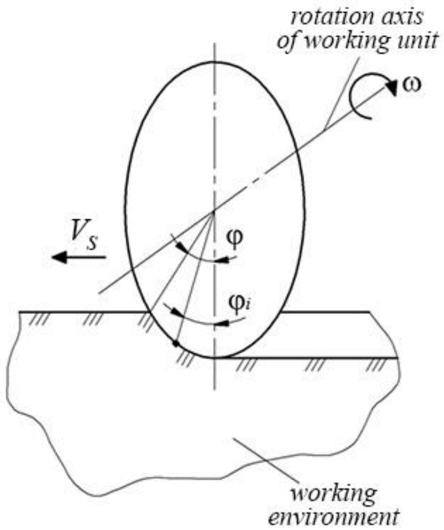

Fig. 1. Peripheral working unit schematic

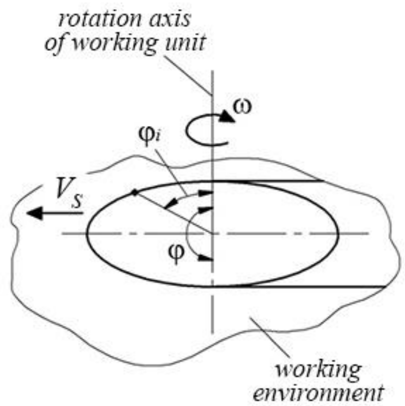

Fig. 2. Front-end first type working unit schematic

Peripheral working units include working units in which the generating working surface of the working environment is parallel to the axis of rotation of the working unit (for example, circular cutters, circular saws). In front-end working units, the generator of the working surface of the working environment is perpendicular to the axis of rotation of the working unit. In the case of the front-end first type working unit, the feed rate is perpendicular to the axis of rotation of the working unit (eg conical cutter), and in the front-end second type working unit it is parallel to this axis (eg column drills). It should be noted that the formation of geometric and kinematic parameters of the development of the working environment in the peripheral working units and front-end working units is identical.

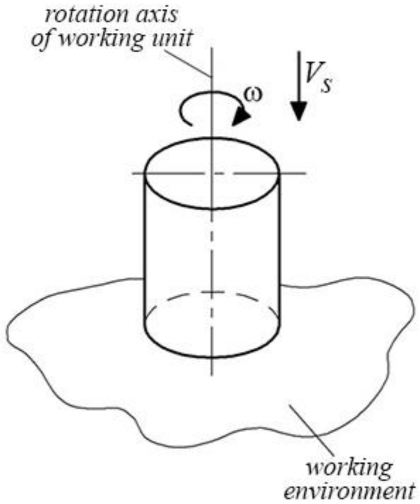

Fig. 3. Front-end second type working unit schematic

The contact area of the cutting element with the working environment in the general case is calculated by the formula

$$S = bh, \tag{4}$$

where
b – width of the cutting element,
h – the depth of cut.

For each of the three types of working units under consideration, the parameter S will differ due to the presence in the expression of a multiplier h that takes into account the differences in the work of each of the presented types of working units. It should be noted that for peripheral working units and front-end second type working units the parameter is used as the width of the cutting elements, while for front-end first type working units the parameter b determines the thickness of the material removed in one pass unit on the working environment.

The calculation of the depth of cut h takes into account the differences in the technology of the working body and, accordingly, allows you to more accurately calculate its power parameters.

When moving the cutting element on a straight-line trajectory, the depth of cut h will be a constant value.

For peripheral working units and front-end first type working units the depth of cutting is variable and for the *i*-th cutting element will be equal

$$h = \frac{\varphi V_s \sin\varphi_i}{\omega}, \tag{5}$$

where
φ – the angle of contact of the working unit with the working environment;
V_s – the speed of supply of the working unit to the working environment;
ω – angular velocity of rotation of the working unit;
φ_i – the angle of contact of the working unit with the working environment, measured from the entrance of the working unit into the face and to the *i*-th cutting element.

For front-end second type working units

$$h = \frac{2\pi V_s \cos(\mathrm{arctg}\frac{V_s}{\omega R_i})}{\omega z}, \tag{6}$$

where
R_i – radius measured from the axis of rotation to the middle of the cutting edge of the *i*-th cutting element;
z – the number of cutting elements in the cutting line (the cutting line consists of elements having the same parameter R_i).

But considering the obtained expressions to determine the depth of cut h, we can see that they allow us to find this parameter for a specific position of the cutting element in the face (for peripheral and end working bodies of the first type). For engineering calculations it is necessary to enter the parameter of average depth of cutting h_{av} which can be used for finding of power parameters of working bodies.

Given the peculiarities of the technology of works by peripheral and front-end first type working units [1,3], the average depth of cut for them will be determined from the expression

$$h_{av} = \frac{V_s(1-\cos\varphi)}{\omega}. \qquad (7)$$

In addition, if you look at the scheme of operation by the front-end first type working unit (Fig. 2), you can see that the angle of contact of the working unit with the working environment φ will be equal π, that is the average depth of cut will be

$$h_{av} = \frac{V_s(1-\cos\pi)}{\omega} = \frac{2V_s}{\omega}. \qquad (8)$$

For front-end second type working units, it is first necessary to determine the average cutting radius:

$$R_{av} = \frac{R_{\max} + R_{\min}}{2}, \qquad (9)$$

Where
$R_{\max}$ – the outer radius of the working body and $R_{\min}$ – the inner radius of the working body

Knowing the average cutting radius, you can calculate the average depth of cut for the front-end second type working units from the expression

$$h_{av} = \frac{2\pi V_s \cos(\mathrm{arctg}\frac{V_s}{\omega n_{c.l} R_{av}})}{\omega z}, \qquad (10)$$

where
$n_{c.l}$ – the number of cutting lines on the working unit.

Given the dependences for determining the average depth of cut h_{av}, you can write formulas for calculating the average contact area of the cutting elements with the working environment:

– for peripheral working units we will have

$$S_{av} = bh_{av} = \frac{bV_s(1-\cos\varphi)}{\omega}; \qquad (11)$$

– for front-end first type working units we will write

$$S_{av} = \frac{2bV_s}{\omega}; \qquad (12)$$

– for front-end second type working units we will receive

$$S_{av} = \frac{2b\pi V_s \cos(\mathrm{arctg}\frac{V_s}{\omega n_{c.l} R_{av}})}{\omega z}. \qquad (13)$$

The average tangential cutting force, taking into account the technology of the working bodies, is determined by the formulas:

– for the peripheral working unit

$$P_{av} = \frac{Uk_d bV_s(1-\cos\varphi)}{2\omega^2 Vk_\alpha}, \qquad (14)$$

– for the front-end first type working unit

$$P_{av} = \frac{Uk_d bV_s}{\omega^2 Vk_\alpha}, \qquad (15)$$

– for the front-end second type working unit

$$P_{av} = \frac{Uk_d b\pi V_s \cos(\mathrm{arctg}\frac{V_s}{\omega n_{c.l} R_{av}})}{\omega^2 Vk_\alpha}. \qquad (16)$$

These dependencies can be applied to working units that have a diamond or abrasive solid cutting edge or similar cutting segments. In addition, certain dependencies can be applied to working units with cutting elements located in the same cutting line (circular saws, core drills, grinding and polishing discs, etc.). Another criterion is the constant radius of the working unit, which provides the same values of kinematic parameters and characteristics of

ISSN(online)2709-6149. Mining, constructional, road and melioration machines, 98, 2021, 5-10

the working process (for example, finger cutters).

In further work there is a need to determine similar parameters for working units with the spatial location of the cutters and the complex geometry of the face. We are talking about the working units (disk, ring, rotary, conical cutter), which at different times were developed at the Department of Construction Machinery named Yu. O. Vetrov of Kyiv National University of Construction and Architecture. The peculiarity of their location in the face, the specifics of the work, the presence of many cutting lines with variable kinematic parameters of the working process and the change in diameter of the working unit in height determine the features of the calculation of the working process.

The obtained dependences for the calculation of the average tangential cutting force allow us to proceed to the determination of energy parameters (cutting power and specific productivity) of peripheral and front-end working units.

CONCLUSIONS

Analyzing the obtained dependences, it should be noted that the technological features of high-speed working units have a significant impact on determining the cutting forces of soils due to the peculiarities of cutting depth calculations for peripheral and end working units. When carrying out engineering calculations of such working units it is necessary to use average values the depth of cutting and the area of contact by a cutting element with the working environment.

Promising in further research is the optimization of the design parameters of the considered working units to reduce the energy intensity of the process of soil destruction.

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Відмінності розрахунків високошвидкісних робочих органів в залежності від кінематики їх робочих процесів

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Анотація. Теорія руйнування робочих середовищ під дією високошвидкісних навантажень різного виду з урахуванням зміни контактних властивостей середовищ, енергії, швидкості і форми робочого органа і часу руйнування лягла в основу сучасних методів розрахунків і створення робочих режимів і конструкцій грунто- і породоруйнуючої техніки і сьогодні використовуються для створення нової техніки.

Динамічне руйнування ґрунтів є молодим напрямком розвитку землерийної техніки, який має достатньо велику кількість невирішених до цього часу завдань, одним з яких є врахування кінематичних особливостей та технології про-

ведення робіт високошвидкісними периферійними та торцевими робочими органами.

Конструктивні параметри цих робочих органів повинні враховувати не тільки динамічні параметри процесу руйнування, але і явища накопичення втомлювальних деформацій в робочому середовищі.

Також необхідно враховувати, що напружено-деформований стан середовища в зоні різання носить коливально-хвильовий характер, подібний до того, який формується при ударно-вібраційному руйнуванні ґрунтів, що є найбільш ефективним динамічним процесом руйнування робочих середовищ. Такий напружено-деформований стан створює умови для накопичення в матеріалі втомлювальних деформацій, тому межа міцності робочого середовища значно зменшується.

Для ефективного низькоенергоємного руйнування матеріалів конструктивні параметри робочих органів повинні визначатися із системного аналізу їх робочих процесів та відповідати умовам втомлювального руйнування матеріалу.

Аналізуючи отримані залежності, слід зазначити, що технологічні особливості високошвидкісних робочих органів мають значний вплив на визначення зусиль різання ґрунтів через особливості розрахунку глибини різання для периферійних і торцевих робочих органів обох типів. При проведенні інженерних розрахунків таких робочих органів необхідно використовувати середні значення глибини різання та площі контакту ріжучого елемента з робочим середовищем.

Ключові слова: периферійний робочий орган, торцевий робочий орган першого типу, торцевий робочий орган другого типу, середня глибина різання, сила різання.