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# SUPERPOSITION PRINCIPLE OF IMPACT ON THE WORKING ENVIRONMENT OF ACTUATING ELEMENTS FOR SITE PREPARATION MACHINES

**Prystailo M., Balaka M., Mozharivskyi V., Drachuk V., Honta I.**
**Kyiv National University of Construction and Architecture**

***Abstract.*** *The article proposes the superposition principle of the influence of several factors on the working environment at the same time, such as static and dynamic load, thanks to the accumulation of energy to create a high-speed force pulse on the cutting edge with the aim of pre-forming a compressed zone in the array, which will reduce the energy intensity of the process.*
***Key words:*** *ripper-pick, soil destruction, power intensity reduction, tip with the dynamic cutting edge, superposition principle.*

## Introduction

There are ripper designs that have significant differences compared to known solutions. An operation productivity increase is achieved due to them with a simultaneous decrease in energy consumption to ensure the technological process [1–4]. Thus, one of the recommendations for constructive updating is based on the productivity improvement task of the preparatory works.

The inertial working element of the ripper contains essential distinctions, since the new characteristics do not coincide with the previously known ones. Thus, the tip has a cutting plate, where the back part is made in step form, and the upper part rests against the body, which can move freely in the tip cavity. The body mass is much larger compared to a cutting plate mass. The task is solved because the ripper working element tip has a moving mass that performs inertial blows on the cutting-edge plate [5].

## Analysis of publications

The inertial working element of the ripper can be used in those cases when it is necessary to destroy solid and frozen soils [6]. It consists of rack 1 and tip 3 set on it with pin 2 (Fig. 1). The latter has a wedge-shaped case 4, which has the mounting eye 5 with fixing hole 6, the front 7 and lower 8 surfaces, which has the «swallow tail» form 9, where the cutting plate 10 is inserted, which has the «swallow tail» protrusion 11 on top. The bush 12, whose surfaces are equidistant surfaces of the groove 9, made of antifriction material, is inserted into the groove 9 between the plate protrusion 10. The cutting plate 10 has the lower surface 13 and the front inclined surface 14, which form a cutting edge 15 at the intersection. Step 16 is made in the back part of plate 10, where the upper part can rest against cylinder 17, and the lower part can go beyond the back dimension of case 4. The cylinder 17 is contained in the cylindrical hole 18 made in case 4. The slot 19 for step 16 and a thread, into which plug 20 is screwed, are made in the back part of cylinder 17.

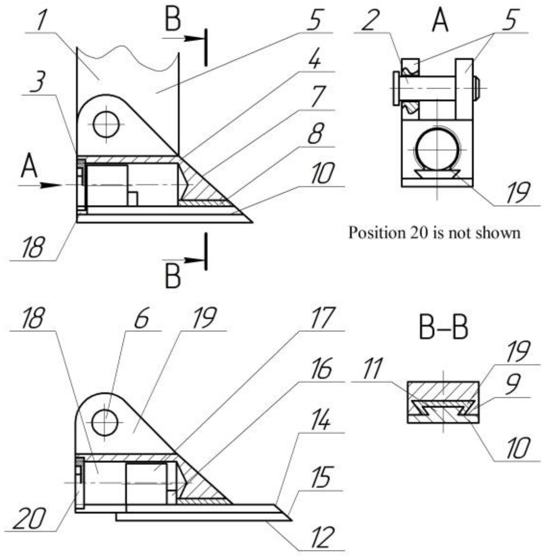


Fig. 1. Inertial working element of the ripper

The inertial working element of the ripper operates as follows. The soil resistance force to cut acts on the cutting edge 15 and pushes plate 10 back together with cylinder 17 when the ripper working element 3 interacts with the soil.

The soil is crumpled by the frontal 7 and front inclined 14 surfaces when the tip is further inserted in him. As a result, the soil element is separated. The soil resistance to cutting decreases significantly at this moment and then increases again. The working element moves in jerks at a non-constant speed. As a result, cylinder 17 at the movement deceleration of the working element continues to move inertial and pushes forward the cutting plate 10 with the cutting edge 15, which additionally cuts the soil, where leading cracks are formed. The torn-off soil element is removed next by the frontal surface 7 to the bottom surface of the face. The cutting plate 10 is pushed back and the upper part of step 16 leads cylinder 17 to the back part of case 4 under the action of soil resistance force to the cutting. The process then proceeds cyclically.

The next recommendations for design improvement were also developed to reduce the dynamic loads in the elements [5].

The working element of the ripper-pick consists of rack 1 and tip 3 set on it with pin 2 (Fig. 2). The latter has the wedge-shaped case 4, which has the mounting eye 5 with fixing hole 6, the front 7 and lower 8 surfaces.

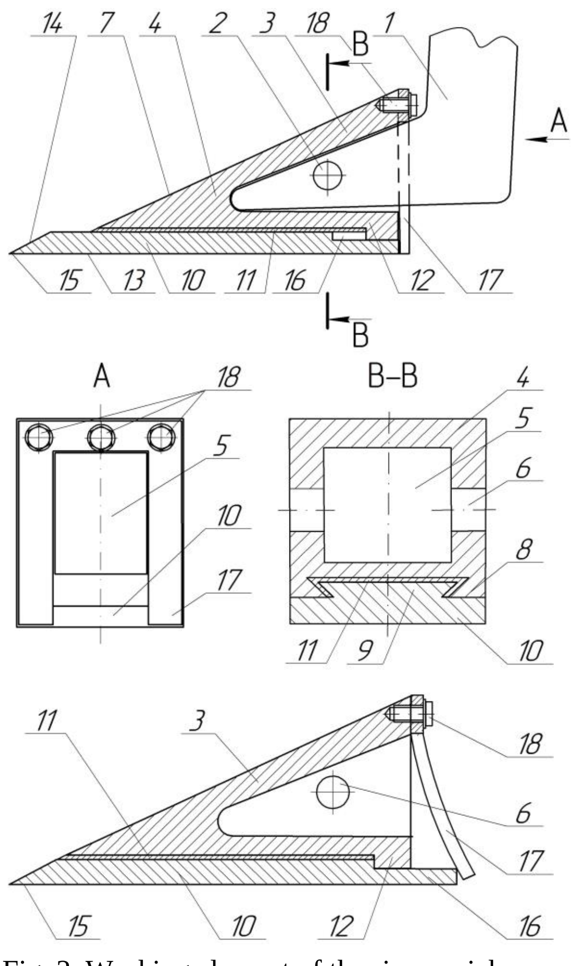


Fig. 2. Working element of the ripper-pick

The lower surface 8 has the «swallow tail» form 9, where the cutting plate 10 is inserted, which has the «swallow tail» protrusion 11 on top. The bush 11, whose surfaces are equidistant surfaces of the groove 9 is inserted into the groove 9 between the plate protrusion 10. The bush 11 is made of anti-friction material and abuts the back part against the limiting stop 12 of the lower surfaces 8. The cutting plate 10 has a lower surface 13 and a front inclined surface 14, which is at the intersection from the cutting edge 15. Step 16 is made in the back part of plate 10, her upper part can rest against stop 12, and the lower part can go beyond the back dimensions of case 4. U-shaped spring 17 is attached to the back part of case 4, the crossbar is attached to case 4 by bolts 18, and the spring struts 17 rest against the lower part of step 16.

The working element of the ripper-pick operates as follows. The soil resistance force to cut acts on the cutting edge and pushes the cutting plate back to the limit stop when the tip interacts with solid or frozen soil. The lower part of the step elastically deforms the spring. The soil is crumpled by the frontal and front inclined surfaces when the tip is further inserted into the soil. As a result, the soil element is separated. The soil resistance to cutting is significantly reduced at this moment. The spring sharply pushes forward the plate with the cutting edge, which additionally cuts the soil, where it forms leading cracks. The torn-off soil element is removed from the frontal surface to the bottom surface of the face. The cutting plate again moves to the limiting stop under the influence of soil resistance to cutting, where it compresses the spring with the step lower part. The process then proceeds cyclically.

Machines with traditional working elements cannot provide the necessary rate of increase in labor productivity in construction because of the large volumes of earthmoving works, including in the winter period [2–4, 6]. The problem solution lies in establishing the process regularities of the soil massif developed with the ripper, the tip of which is equipped the cutting edge with a pneumatic accumulator [7]. As a result, the accumulation of potential energy is ensured with its further transformation into kinetic energy and direction into the soil massif at its compaction.

The process of energy accumulation and transformation occurs with the tip that has the next design (Fig. 3): a stand with tip 1, which has the movable cutting edge 2, connected by finger 3 to pneumatic cylinder 5 rod 4, which moves the cutting edge 2 by $L$ distance.

The analysis of the available designs for the ripper working elements showed that a perspective direction for their improvement is the use of vibration and impact actuating elements. These elements operate on the principle of dynamic energy accumulation, with its subsequent use in the soil destruction process.

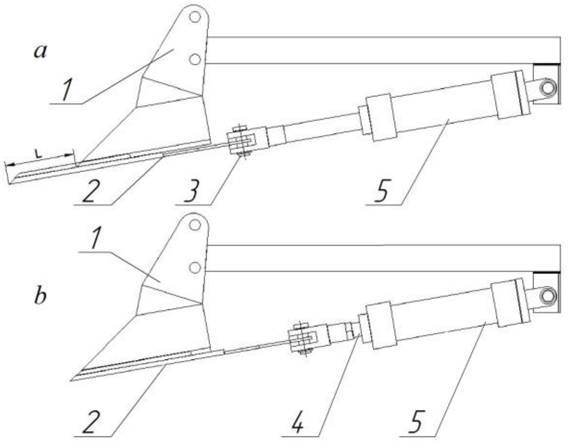


Fig. 3. Tip with cutting edge on the pneumatic cylinder: (a) working position with cutting edge, (b) sharp knife

### Purpose and problem of the paper

The purpose of the paper is the main hypothesis formation of the impact superposition principle on the working environment of actuating elements for ripper-pick and its justification in the result combine the work of static force, determined by the traction parameters of the ripper, and the work of dynamic forces, determined by the physical and mechanical conditions of the soil destruction process.

### Research results

The dependence between the resistance $P$ force of the working element, the cutting edge $b$ width of the working element and $h$ depth of its penetration into soil, established in the paper [1] on the determination of soil resistance to digging by construction machine, has the form:

$$P = k \cdot b \cdot h, \tag{1}$$

where $k$ – specific resistance to soil digging by the working element.

This expression was proposed for the excavator bucket by M. Dombrovskyi [2], but it can also be used for rippers when performing approximate comparable calculations.

A. Zelenin performed the first fundamental research on the destruction physics process of frozen soil by the ripper tooth. His research and the research of other authors [1, 2, 4] made it possible to distinguish two stages of the destruction process of the solid environment by the ripper working element. Compression deformations are accumulated in the first stage. It leads to the soil zone formation in front of the working element tooth, which is in a volumetric strained state. These deformations reach the critical value and fracture destruction, that is, the environment element is chipped in the second stage. The area of the critical state of soil deformations extends over the entire destruction volume for melted plastic soils. The stresses reach a critical level when the soil fragility, as a result, a chipping element is formed, the appearance of the so-called mobile crack.

The destruction process of frozen soil is a complex deformation in most cases, which creates difficulties in the analytical description of the loosening process.

Reaches of irreversible deformations, plastic deformations, and reaches in which soil destruction is already occurring appear, and sometimes simultaneously exist when the working element is buried in the soil. Each of them is described by the different methods of materials mechanics [4].

A. Zelenin established that the soil volume is transformed into a compacted core when the working element is moved. This core with significant consistency is in the volumetric stress state. It is like an extension of the tip of the working element about the rest of the material mass and contributes to soil rupture. The formula proposed by A. Zelenin for determining soil loosening resistance has the form [2]:

$$\begin{aligned} P = \xi h b \sigma_p \sin(90^\circ - \frac{\alpha + \varphi + \sigma_p}{2}) + \\ + 10 c h_2 \sqrt{b}\left(1 + \frac{\alpha - 30}{80}\right)\mu_0 \Delta_0, \end{aligned} \tag{2}$$

where $\xi$ – actual area ratio of soil detachment to the conditional area $hb$; $h$ – destruction depth; $b$ – tooth width (A. Zelenin used the mark $S$, here and in the future we use the mark $b$ for the convenience of comparing the equations); $\sigma_p$ – breaking strength of the soil; $\alpha$ – cutting angle; $\varphi$ – angle of internal friction; $c$ – blows number of the dynamic densimeter of the road research institute; $h_2$ – depth of the cut slot lower part; $\mu_0$ – friction angle of steel on soil; $\Delta_0$ – factor that takes into account the blunting degree of the working element.

The first component of the equation is the horizontal component of the separation force, the second is the cutting force across the area. As you can see, cutting in the reach of the cutting edge is not highlighted and is not considered separately.

Many determination studies of the cutting critical depth and the wear effect or blunting of the working element on the resistance to cutting (loosening) were carried out by Yu. Vietrov [1, 2, 8]. He considered the force of resistance to cutting (loosening) $P_W$ as the force sum to overcome the soil resistance by the knife front face $P_w$, the force to overcome the soil resistance to destruction in the lateral expansions of the cut slot $P_s$, the force to overcome the soil resistance to the cut by the knife side ribs near the cut slot bottom $P_{s.c}$, and the additional cutting force from the wear area (dulling) $P_{d.z}$ [8]:

$$P_W = P_w + P_s + P_{s.c} + P_{d.z}\,; \tag{3}$$

$$P_w = p_w F_w = p_w bh = m_w bh\,; \tag{4}$$

$$P_s = p_s F_s = p_s k_s^2 h^2 ctg\gamma = 2m_s h^2\,; \tag{5}$$

$$P_{s.c} = p_{s.c} L_{s.c} = 2p_{s.c}(1 - k_{s.c})h = 2m_{s.c} h\,; \tag{6}$$

$$P_{d.z} = p_0 + p_d \frac{h}{h + h_d}\,, \tag{7}$$

where $p_w$, $p_s$, $p_{s.c}$ – specific forces; $F_w$, $F_s$ – cross-sectional area of the cut in the soil at the knife front face and the side part; $L_{s.c}$ – length of the cut line by the knife side edge; $b$ – cut width; $m_w$ – specific cutting force to overcome soil resistance by the knife (tooth) front edge at 45° cutting angle; $k_s$ – depth factor of the expanding cut slot; $\gamma$ – inclination angle of the cut slot sidewall in the soil; $m_s$, $m_{s.c}$ – factors characterized the specific forces of soil resistance to destruction in lateral extensions and cutting by the knife lateral edges; $p_0$ – additional force of resistance to the blunt knife at zero cutting depth; $p_d$ – difference between the limit value of the additional force for this soil and its value at zero depth; $h_d$ – cutting depth corresponds to the additional cutting force $p_0 = 0{,}5p_d$.

High-speed cutting by the theory of V. Baladynskyi is based on the propagation of the deformation wave [9]. A certain amount of energy $E_{sh}$ is transferred from the working element to the soil per unit surface $S$ of the soil massif that is being destroyed. This energy, to the law of conservation of energy, is spent on the soil elastic deformation $E_{cp}$ and on the formation of new soil surfaces (its destruction) $E_p$:

$$E_{sh} = E_{cp} + E_p \tag{8}$$

or taking into account load parameters and soil characteristics, the resistance force $P_D$ is determined by the next dependence:

$$P_D = \frac{uk_d S}{2vk_\alpha}\,, \tag{9}$$

where $u$ – propagation speed of the deformation wave in the soil massif; $k_d$ – soil specific resistance to dynamic destruction; $v$ – introduction speed; $k_\alpha$ – factor of the sharpening angle.

As can be seen, the destruction of the soil during the high speed of working element introduction is described. So, it is impossible to apply this theory to the working element with the cantilever-mounted cutting edge. High speeds occur only on the cantilever-mounted cutting edge, and the working element is fed at a lower speed than 10 m/s [3].

There are many methods to calculate the working elements of ripper-picks, which fully and with sufficient accuracy reflect the loosening process of the soil. However, they cannot be used to calculate the destruction of strong soils by the proposed working elements. Such a method of soil destruction can only conditionally be called static at low speed of force application. The resistance to solid and frozen soils destruction changes significantly in the chipping process (torn-off of the chip element).

The amplitude of the cutting force change for solid and frozen soils is on average 70 % of the medium maximum value [4, 6]. Such force vibrations determine the dynamic effects on the working equipment and the dynamics of the soil destruction process itself. Also, such the process cannot be called a hundred percent dynamic, since the introduction speed of the working element into the soil does not exceed 10 m/s.

Considering soil cutting by the knife with elastically deformed actuating elements would be appropriate as a combined process with static and dynamic cutting properties. However, there is information based on which it is possible to develop the necessary theory by the superposition principle of effecting several factors simultaneously, such as static cutting and high-speed cutting.

Combining expressions (3) and (9) into one system, we get:

$$P_S = P_W + P_D\,. \tag{10}$$

The values of the components are substituted into expression (10) and an equation is obtained, which describes the interaction between the soil and tip equipped with the dynamic cutting edge, where the edge frontal surface is parallel to the tip frontal surface.

The mathematical model describes the soil destruction process by the tip with the dynamic cutting edge. It combines the work of static forces, determined by the traction force of the base machine, and the work of dynamic forces, caused by the physical and mechanical conditions of the soil destruction process [10].

To the energy change theorem, the work $A$ done in the researched system is equal to the kinetic energy change in the same system

$$A = \Delta U_{Ck} = U_{Ck2} - U_{Ck1}, \quad (11)$$

where $\Delta U_{Ck}$ – kinetic energy change; $U_{Ck2}$ – final value of kinetic energy; $U_{Ck1}$ – current value of kinetic energy.

To chip the soil element from the massif by a simple sharp knife, work $A$ must be performed. The same work $A$ must be performed to chip the same soil element from the massif by the tip with the dynamic cutting edge [7, 11].

So, the work $A$ in the first case is equal to the work sum of forces to overcome the resistance of the soil to cutting by the simple sharp knife (tip) $P_W$ – tangential component of the force to overcome the resistance of the soil to cutting; $N_W$ – normal component of the force to overcome the resistance of the soil to cutting:

$$A = A_{P_W} + A_{N_W} = P_W \cdot l_c + N_W \cos\Omega \cdot l_c, \quad (12)$$

where $l_c = v \cdot T_c$ – travel by the knife from the contact begins with the massif to the complete chipping of the soil element (Fig. 4, a).

In another case (Fig. 4, b), the work $A$ is equal to the work sum: of static forces $P_S$ – tangential component of the force to overcome the resistance of the soil to cutting, $N_S$ – normal component of the force to overcome the resistance of the soil to cutting; of dynamic forces $P_D$ – tangential component of cutting force, $N_D$ – normal component of cutting force acting in the area of dynamic cutting edge; $P_B$ – forces for bringing the cutting edge; $l_d$ – travel by the cutting edge.

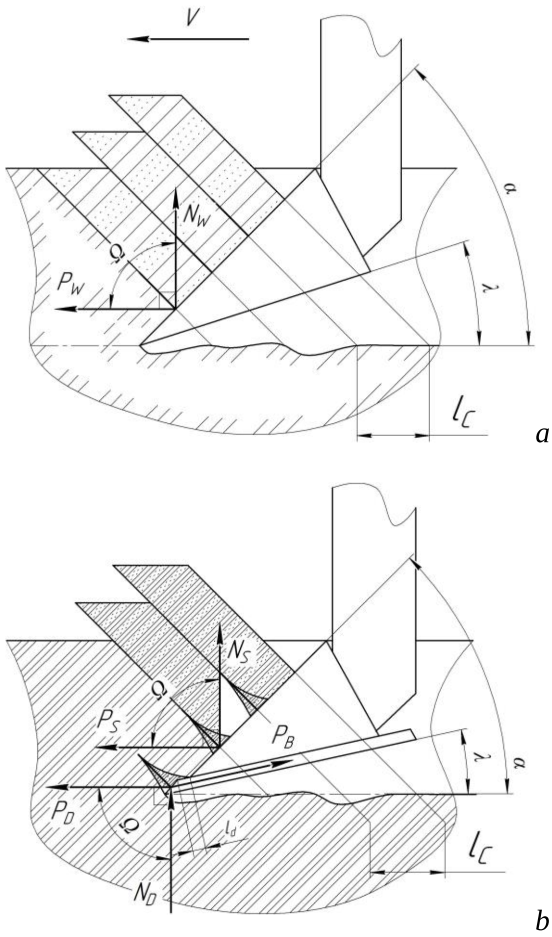


Fig. 4. Determination schemes of forces work when soil cutting *(a)* by simple sharp knife, *(b)* by tip with the dynamic cutting edge

$$\begin{aligned} A &= A_{P_S} + A_{N_S} + A_{P_D} + A_{N_D} + A_{P_B} = \\ &= P_S \cdot l_c + N_S \cos\Omega \cdot l_c + P_D \cdot l_d \sin\lambda + \\ &+ N_D \cos\Omega \cdot l_d \sin\lambda - P_B \sin\lambda \cdot l_d \sin\lambda. \end{aligned} \quad (13)$$

An expression (12) will take the next form, given that $\Omega = 90$, and $\cos 90 = 0$:

$$A = P_W \cdot l_c, \quad (14)$$

and expression (13) will have the form

$$A = P_S l_c + P_D \cdot l_d \sin\lambda - P_B \sin\lambda \cdot l_d \sin\lambda,$$

where $\lambda$ – cutting back angle.

Simplifying this expression, we get

$$A = P_S l_c + \left(P_D l_d - P_B \sin\lambda\right) \cdot l_d \sin\lambda. \quad (15)$$

Equating expressions (14) and (15), we get

$$P_W l_c = P_S l_c + \left(P_D l_d - P_B \sin\lambda\right) \cdot l_d \sin\lambda. \quad (16)$$

We find an expression from here

$$P_S = P_W - \left(P_D l_d - P_B \sin\lambda\right) \cdot l_c \cdot l_d \sin\lambda . \quad (17)$$

## Conclusions

We applied the superposition principle of effecting several factors on the working environment concurrently, such as static and dynamic load. This is due to the possibility of energy accumulation with its subsequent use to create the high-speed power pulse on the cutting edge to ensure the preliminary formation of the compressed zone in the massif. This will lead to power intensity reduction of the static load for complete separation of the soil element.

The presented model describes the soil destruction process by the tip with the dynamic cutting edge. It combines the work of static force, determined by the traction force of the base machine, and the work of dynamic forces, caused by the physical and mechanical conditions of the soil destruction process. This will make it possible to develop the technological basis for the creation and application of such systems. To determine the mechanism of their interaction taking into account changes over time and to develop fundamentally new technical solutions, to create effective, safe and durable working elements.

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**Mykola Prystailo,** Cand. Sc. (Engineering), Associate Professor of Construction Machines Department, prystailo.mo@knuba.edu.ua,
**Maksym Balaka,** Cand. Sc. (Engineering), Associate Professor of Construction Machines Department, balaka.mm@knuba.edu.ua,
**Valentyn Mozharivskyi,** candidate for the Doctor of Philosophy degree in the specialty 133 Industrial machinery engineering, kompass@ukr.net,
**Volodymyr Drachuk,** candidate for the Doctor of Philosophy degree in the specialty 133 Industrial machinery engineering, vdv2882@gmail.com,
**Ihor Honta,** candidate for the Doctor of Philosophy degree in the specialty 133 Industrial machinery engineering, honta_ip-2022@knuba.edu.ua,
Kyiv National University of Construction and Archi-

tecture, 31, Povitrianykh Syl Ave., Kyiv, 03037, Ukraine.

**Принцип суперпозиції впливу на робоче середовище виконавчих елементів машин для підготовчих робіт**

***Анотація.*** *У статті запропоновано принцип суперпозицій впливу на робоче середовище декількох чинників одночасно, зокрема таких, як статичне та динамічне навантаження, завдяки акумулюванню енергії для створення швидкісного силового імпульсу на різальній кромці з метою попереднього утворення стисненої зони в масиві, що зменшить енергоємність процесу.*

***Ключові слова:*** *розпушувач-кайлувальник, руйнування ґрунту, зменшення енергоємності, наконечник з динамічною різальною кромкою, принцип суперпозицій.*

**Пристайло Микола Олексійович,** канд. техн. наук, доцент кафедри будівельних машин, prystailo.mo@knuba.edu.ua,
**Балака Максим Миколайович,** канд. техн. наук, доцент кафедри будівельних машин, balaka.mm@knuba.edu.ua,
**Можарівський Валентин Петрович,** здобувач вищої освіти ступеня доктора філософії за спеціальністю 133 Галузеве машинобудування, kompass@ukr.net,
**Драчук Володимир Володимирович,** здобувач вищої освіти ступеня доктора філософії за спеціальністю 133 Галузеве машинобудування, vdv2882@gmail.com,
**Гонта Ігор Петрович,** здобувач вищої освіти ступеня доктора філософії за спеціальністю 133 Галузеве машинобудування, honta_ip-2022@knuba.edu.ua,
Київський національний університет будівництва і архітектури, просп. Повітряних Сил, 31, м. Київ, 03037, Україна.