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Modeling of the stability of elements of attached equipment of the rock-destroying working item of the construction machine

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Abstract. The materials of the article are devoted to the issue of simulation modeling of the stability of the elements of the attached equipment of the rock-crushing work equipment of the construction machine for earthworks. Today, an urgent task is to perform earthworks in a short time with mobile machines. Such a need exists in the formation of trenches, in particular, in the laying of main pipelines. A feature of the need for rapid formation of trenches for the laying of main pipelines is the mobility of the basic equipment. In order to create competitive technical solutions in the field of construction mechanization, in particular, when performing earthworks, it is necessary to perform project work on improving existing solutions and creating new ones using simulation modeling methods.

The developed rock-destroying working body for earthworks works in conditions of dynamic destruction. Its design is developed taking into account the possibility of using it on existing equipment. Thus, it is proposed to use the base machine of the 2nd power class with a diameter of a disc rock-destroying organ of 600 mm when it works in soils of category IV.

To implement the synthesis of the drive of the rock-crushing working body with the existing equipment of the base machine, a modular frame structure is proposed, which provides the functions of "fixation", "immersion", "movement" of the working equipment.

A computer geometric model of the attached equipment was created, in the formation of which the approaches of form formation with implicitly expressed dimensions and parameters of geometric arrays were used, which allows to optimize the design process taking into account feedback as a result of simulation modeling of processes and experimental studies, and to use it in the formation of an information model construction process during earthworks.

Keywords: excavator, working equipment, frame, stability.

INTRODUCTION

The issue of modeling the stability of elements of constru

ction machines is acute during the creation of new working bodies or the study of existing ones during their work in new conditions.

The works of Harnets V., Nazarenko I., and Khmara L. are devoted to the issue of creating new structures of the working bodies of construction machines.

The issues of research on the destruction of working environments, in particular soils, are devoted also at the scientist's works Vetrov V. [1], Baladinskyi V. [2], Nazarov V. [3], Nichke V. [3, 4], Kravtsia S. [5], Khmara L. [6],

Ukrainian scientists, such as Vlasov V. [7], Smirnov V. [7], V. Sivko [8], Moiseyenko V. [9], Myroshnychenko K. [10], Blokhin V. [11], Malich M. [11], Karaev O. [12], Kuzminets M. [13], Musiyko V. [13], Nazarenko I. [14], Sukach M. [15], Garnets V. [16] and others were engaged in the issue of modeling the behavior of the working equipment of rock-destructive working items of construction machines.

At the department of construction machines of KNUBA, a rock-destroying working body of a construction machine was developed for the execution of earthworks, in particular, the laying of main pipelines [17, 18].

Under the specified conditions of dynamic destruction, the strength of soil and rock resistance to destruction depends on the speed V_0 of the introduction of the working body into the massif, the compressive strength limit $\sigma_Д$ of the soil, its deformation modulus $E_Д$ (MPa), specific gravity $\gamma_Г$, density $\rho = \gamma_Г / g$, the coefficient Poisson's μ, the specific dynamic resistance to destruction $K_Д$, the speed of the waves the values of the velocity of the waves of deformations U, the specific resistance of the soil to destruction $K_Д$ are determined; strength of soil resistance to destruction P, the average period of fluctuations of the cutting force t [1].

The speed of cutting force fluctuations [2]:

$$V_K = \frac{U}{K-1},$$

where K – the number of pulses required to destroy an array element.

The speed of introduction of the cutting element into the array [2, 7]

$$V_0 = \sqrt{V_M^2 + (V_P + V_K)^2 - 2V_M (V_P + V_K)\cos(\omega t)}.$$

Specific resistance to destruction [2]:

$$K_Д = \rho V_0^2 + \varepsilon_Д \sigma_Д,$$

where $\varepsilon_Д$ – relative deformation of the working environment; ρ – soil density; $\sigma_Д$ – compressive strength of the soil.

The strength of soil resistance to destruction in the oscillatory mode [2]:

$$P_K = \frac{UK_Д S}{2V_0 K_\alpha},$$

where S – the area of contact of the working body with the soil; U – rate of passage of deformation waves; m – the mass of the working body; K_α – coefficient that takes into account the sharpening angle of the cutting element.

The limit value of the value of the entry of the cutting element into the array in the oscillating mode [2]:

$$\delta = \frac{2E_{ПИТ} K_\alpha V_K}{SUK_Д},$$

where S – contact area of cutting elements with the ground.

The depth of introduction of the cutting element into the array in one pulse:

$$h_p = V_2 \left[\left(\frac{1}{K} \right) \sqrt{m_p l_i} \right] \sqrt{m_p l_i},$$

where $K = \tau \left(\rho V_2^2 S + 2S \int_0^\varepsilon f(\varepsilon) d\varepsilon \right)$; τ – pulse time; m_p – mass of moving parts of the working item; V_2 – speed of the working item at the moment of impulse.

The required number of oscillations

$$n_K = \frac{\delta}{h} = \frac{2E_{ПИТ} K_\alpha}{Um_P} \frac{\tau}{l_i}.$$

The coefficient α is characterizes the correlation between the physical and mechanical properties of the soil and the drive parameters of the end working body with controlled power parameters

$$\alpha = V_2 \frac{\sqrt{m_p l_i}}{\tau \left(JV_2^2 S + 2S \int_0^\varepsilon f(\varepsilon) d\varepsilon \right)}.$$

Impulse work

$$A_{ИМП} = p_{ИМП} \frac{\omega_K}{2\pi} q_{ДВ} \tau,$$

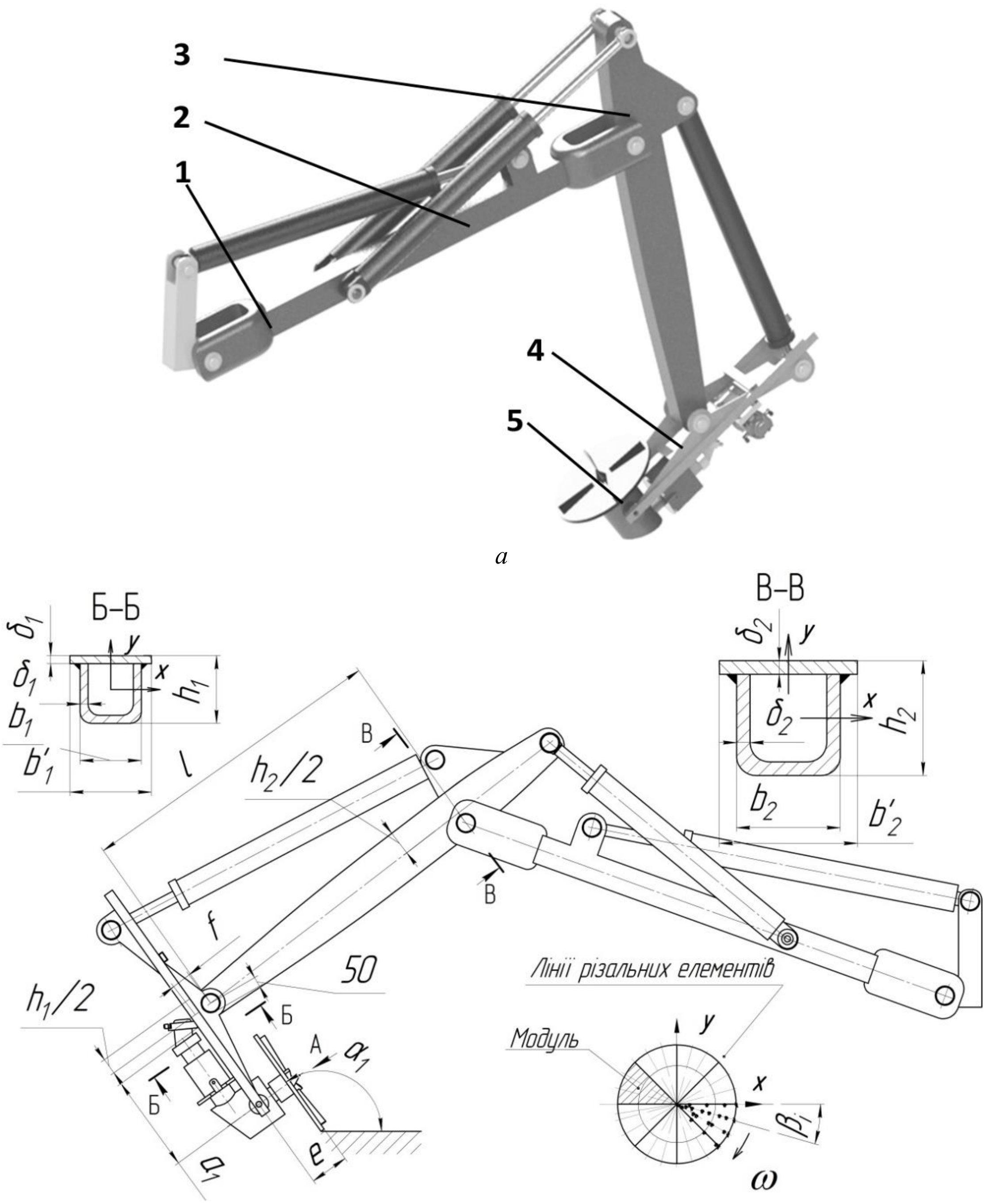
where $p_{IМП}$ – pressure pulse increase in the drive system of the working body; ω_K – angular velocity of oscillations; $q_{ДВ}$ – specific volume of the drive motor; τ – pulse time.

Energy intensity of the oscillatory process

$$e = \frac{n_K A_{IМП}}{Sl_i}.$$

Relative dynamic effect:

$$\Delta = \frac{P - P_K}{P},$$



b

Fig. 1 Mounted working earthmoving equipment of the disk type for the formation of trunk channels: *a* – general view (3d model); *b* – calculation scheme: *1* – basis; *2* – excavator boom; *3* – excavator handle; *4* – the frame of the working item; *5* – working item.

where P та P_K – strength of soil resistance to destruction, respectively, in pulseless and pulsed modes.

Let's consider the attached equipment of the earthmoving machine with a disc-type rock-destroying working body for the formation of main channels (Fig.1) [17, 18]

The destructive working item is a disk, on the front surface of which cutting and throwing elements are installed. Cutting elements are installed according to a modular scheme and form cutting lines, which in turn form cutting modules. Cast elements separate the cutting modules from each other.

To implement the optimized trajectory of the working body deepening, the frame of the disc working body is designed [18].

The modular frame provides the functions of "fixation", "immersion", and "movement" of the working equipment.

The main indicators that determine the effect on the attached equipment will be: M_z, Q_z – bending moment and transverse force during bending in the plane of the working equipment; M_y, Q_y – bending moment and transverse force when bending out of the plane of the working equipment; T – torque; n_1 – the number of simultaneously working cutting elements of the disk; N – longitudinal force.

Let's determine the parameters of the intersection Б-Б.

Bending moments

$$M_z = -e\sum_{i=1}^{n_1} P_i \sin\beta_i + \sum_{i=1}^{n_1}\left[\frac{d_i}{2}\sin\beta_i + a_1\right]N_i ,$$

$$M_y = -\sum_{i=1}^{n_1} P_i \cos\beta_i\left[a_1 + \frac{d_i}{2}\cos\beta_i\right] - \sum_{i=1}^{n_1} P_i \sin\beta_i \frac{d_i}{2}\sin\beta_i .$$

Torque

$$T = \sum_{i=1}^{n_1} P_i \cos\beta_i\begin{bmatrix} e\cdot\cos(\alpha_1-\alpha_2) - \\ -\frac{d_i}{2}\cos\beta_i\cdot\sin(\alpha_1-\alpha_2)\end{bmatrix} - \sum_{i=1}^{n_1} P_i \sin\beta_i\cdot\sin(\alpha_1-\alpha_2)\frac{d_i}{2}\sin\beta_i + \sum_{i=1}^{n_1} N_i\cos(\alpha_1-\alpha_2)\frac{d_i}{2}\sin\beta_i ,$$

$$T = \sum_{i=1}^{n_1} P_i \cos\beta_i e + \sum_{i=1}^{n_1} N_i \frac{d_i}{2}\sin\beta_i .$$

Longitudinal force

$$N = \sum_{i=1}^{n_1} P_i \sin\beta_i .$$

Transverse force

$$Q_z = \sum_{i=1}^{n_1} N_i , \quad Q_y = \sum_{i=1}^{n_1} P_i .$$

For the intersection B-B, the power indicators will be determined according to the following formulas.

Bending moments

$$M_z = -\sum_{i=1}^{n_1} P_i \sin\beta_i[(l+f)-e] - \sum_{i=1}^{n_1} N_i\left[(a_1+c+h_2/2)+\frac{d_i}{2}\cos\beta_i\right]$$

$$M_y = -\sum_{i=1}^{n_1} P_i \cos\beta_i[l+f-e] + \sum_{i=1}^{n_1} N_i \cos\beta_i \frac{d_i}{2}.$$

Torque

$$T = \sum_{i=1}^{n_1} P_i \cos\beta_i\left[a_1+c+h_1/2+\frac{d_i}{2}\cos\beta_i\right] + \sum_{i=1}^{n_1} P_i \sin\beta_i \frac{d_i}{2}\sin\beta_i .$$

Longitudinal force

$$N = -\sum_{i=1}^{n_1} N_i .$$

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Transverse forces

$$Q_z = \sum_{i=1}^{n_1} P_i \sin\beta_i\,, \quad Q_y = \sum_{i=1}^{n_1} P_i \cos\beta_i\,.$$

Geometric characteristics and tension for box sections

Let's determine the geometric characteristics and stresses for box sections Б-Б та В-В.

Legend: δ_n – shelf thickness, δ_{cm} – wall thickness, k – weld legs, $b' = b + 2k$ during automatic welding, $b' = b + 1{,}4k$ during manual welding.

The distance from the lower points of the section to its center of gravity C, $h_ц$, sm:

$$h_ц = \frac{S_{z1}}{F},$$

where F – cross-sectional area, sm^2; S_{z1}– static moment of the section relative to the axis z_1, sm^3.

$$F = (2h + b - \delta_{cm})\delta_{cm} + b'\delta_n;$$

$$S_{z1} = b'\delta_n(h - 0{,}5\delta_n) + $$
$$+ 2(h - \delta_n)\delta_{cm}\frac{1}{2}(h - \delta_n) + \frac{1}{2}(b - 2\delta_{cm})\delta_{cm}.$$

The moment of inertia of the section relative to the center of the axis z, sm^4:

$$I_z = I_{z1} - h_ц^2 F = \frac{b'\delta_n^3}{12} + \frac{(b - 2\delta_{cm})\delta_{cm}^3}{3} +$$
$$+ \frac{\delta_{cm}(h - \delta_n)^3}{3} + b'\delta_n(h - 0{,}5\delta_n) - h_ц^2 F$$

The moment of inertia of the section relative to the central axis y:

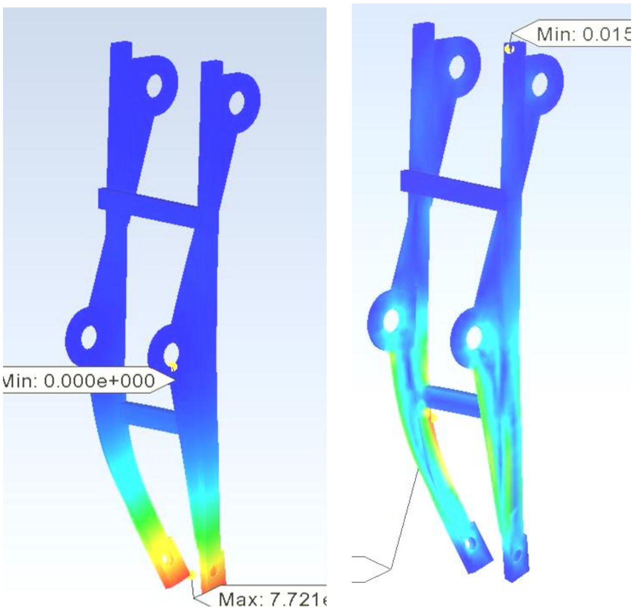
$$I_y = \frac{\delta_n(b')^3}{12} + \frac{\delta_{cm}(b - 2\delta_{cm})^3}{12} +$$
$$+ 2\frac{(h - \delta_n)\delta_{cm}^3}{12} + 2(h - \delta_n)\delta_{cm}\left(\frac{h - \delta_{cm}}{2}\right)^2.$$

Contour area bounded by middle lines:

$$F_1 = (b - \delta_{cm})(h - 0{,}5(\delta_n + \delta_{cm})).$$

Static moment of the upper section relative to the axis z, sm^3:

$$S_z = (b'\delta_n)(h - h_ц - 0{,}5\delta_n) +$$
$$+ 2\delta_{cm}\frac{1}{2}(h - h_ц - 0{,}5\delta_n)^3.$$



a *б*

Fig. 2. The results of computer modeling of loads on the frame of the rock-crushing working item: *a* – movement diagram; *b* – diagram of internal loads

Static moment of the right part of the section relative to the axis y:

$$S_y = \frac{1}{8}\delta_n (b')^2 + \frac{1}{8}\delta_{cm}(b - 2\delta_{cm})^2 + + (h - \delta_n)\delta_{cm}\frac{1}{2}(h - \delta_{cm}).$$

Normal tension:

$$\sigma = \frac{N}{F} + \frac{|M_Z|y}{I_Z} + \frac{|M_y|Z}{I_y}.$$

Verification:

$$y = h - h_ц, \quad Z - 0{,}5b'; \quad \sigma = \sigma_{\max}, \quad \sigma_{\max} \le [\sigma].$$

for steel Ст.3and steel 20 $[\sigma]$=160 МПа.

Tangential tension:

a) for walls

$$\tau = \frac{Q_z S_z}{2I_z\delta_{cm}} + \frac{T}{2A_1\delta_{cm}},$$

б) for the shelf

$$\tau = \frac{Q_y S_y}{2I_y\delta_n} + \frac{T}{2A_1\delta_n}.$$

In order to obtain the maximum value of τ, it is necessary to substitute the statistical moments S_z, S_y obtained above into these formulas:

Verification.

Normal tension:

$$\tau_{\max} \le [\tau]; \quad [\tau] \approx 0{,}5[\tau].$$

Equivalent tension:

$$\sigma_{екв} = \sqrt{\sigma^2 + 3\tau^2} \le [\sigma].$$

The check is performed at the junction points of the walls with the shelf

$$y = h - h_ц - \delta_n, \quad Z = 0{,}5b;$$

$$S_z = S_{nz} = (b'\delta_n)(h - h_ц - 0{,}5\delta_n).$$

According to the obtained dependencies, the loads acting on the structure are determined, as well as the values of internal forces in its elements [19]. When simulating the load on the attachment of disk-type earthmoving equipment for the formation of main channels, geometric computer modeling, the finite element method was used, a picture of displacements and stress nodes was obtained (Fig. 2)

The conducted force analysis of the developed attachment equipment of the mobile machine allows to minimize its material consumption of soil destruction of category IV [1] in dynamic mode [2], to ensure compliance of the depth angle with the least energy-intensive process and, accordingly, to increase the wear resistance of the cutting elements. The obtained data can be used for the development of machines with rock-crushing working bodies, using techniques for optimizing the technical indicators [6].

CONCLUSIONS

1. The developed rock-destroying working body for the formation of main pipelines allows you to implement the tasks of forming trenches in the soil environment with reduced energy-intensive indicators due to the use of qualitative indicators during dynamic destruction.
2. To implement the technological modes of the rock-crushing working body, an adaptive modular frame has been developed that implements the basic functions of the working equipment: fixation, "sinking", "moving".
3. A three-dimensional geometric model of the modular frame of the rock-crushing equipment was formed, in the formation of which methods of shaping with implicitly expressed dimensions and parameters of geometric arrays were used, which allows to optimize the design process taking into account feedback as a result of simulation modeling of processes and experimental studies, and to use it in formation of an information model of the construction process during the execution of earthworks.

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Моделирование устойчивости элементов навесного оборудования породо-разрушающего рабочего органа строительной машины

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Аннотация. Материалы статьи посвящены вопросу имитационного моделирования устойчивости элементов навесного породоразрушающего оборудо-вания строительной машины для выполнения земляных работ. На сегодняшний день актуальной задачей является выполнение земляных работ в сокращенные сроки мобильными машинами. Такая потребность существует при образовании траншей, в частности, при прокладке магистральных трубопроводов. Особенностью потребностей быстрого образования траншей для прокладки магистральных трубопроводов является мобильность базовой техники. Для создания конкурентоспособных технических решений в области строительной механизации, в частности, при выполнении земляных работ необходимо выполнять проектные работы по совершенствованию существующих решений и создания новых с применением методов имитационного моделирования.

Разработанный породоразрушающий рабочий орган для земляных работ работает в условиях динамического разрушения. Его конструкция разработана с учетом возможности использования на существующей технике. Да, предложено использование базовой машины 2 класса мощности при диаметре дискового породоразрушающего органа 600 мм при его работе в грунтах IV категории.

Для реализации синтеза привода породоразрушающего рабочего органа с существующим оборудованием базовой машины предложен конструктив модульной рамы, обеспечивающей функции «фиксации», «углубления», «перемещения» рабочего оборудования.

Создана компьютерная геометрическая модель навесного оборудования, при формировании которой использованы подходы формообразования с неявно выраженными размерами и параметрами геометрических массивов, что позволяет оптимизировать процесс проектирования с учетом обратных связей в результате имитационного моделирования процессов и экспериментальных исследований и использовать его при формировании информационной модели строительного процесса при выполнении земляных работ.

Ключевые слова: экскаватор, рабочее оборудование, рама, устойчивость.