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SUBSTANTIATION OF RATIONAL DESIGN PARAMETERS OF A CRUSHER WITH TWO MOVABLE JAWS

Purpose. Design engineering of the mechanism of a two-jaw crusher with a compound motion of the jaws, which ensures a change in the angle of gripping of pieces of material within a very small range.

Methodology. In the work, a theoretical study on the fourth-class lever mechanism, as the basis of a two-jaw crusher, was performed using the Mathcad 15 software. The study was performed on a vector representation of the links of the hinged mechanism. The development and analysis of constructive solutions were performed using the Autocad software product, which reduces the risk of errors and increases the quality of the design process.

Findings. The paper theoretically determines the rational geometric parameters of the two-jaw crusher with the optimal value of the nip angle, whose crushing chamber is formed by the closed loop circuit of the flat fourth-class lever mechanism and proposes a new constructive solution of the mechanism for adjusting the crusher opening with two movable jaws and the bottom mounting of eccentric nodes. The developed device in the form of separate blocks is made with the possibility of their simple assembly and disassembly, which ensures the rate and quality of replacing lining plates or surfacing restoration of the worn working surface of the jaws. The relative movement of the jaws ensures the crushing of pieces of material with the required crushing coefficient. The geometric parameters were obtained by the method of kinematic synthesis. The geometric parameters of the crushing chamber of the two-jaw crusher were determined theoretically; the dependence was obtained of the change in the nip angle on the height of the movable jaw over a period of movement and the change in the compression stroke, which ensures the force interaction of the working surface of the jaws with the material.

Originality. It is proved that the quadrilateral closed circuit of the fourth-class lever mechanism can be used as a crushing chamber of a two-jaw crusher. Two links of a closed circuit operate as jaws which break pieces of material. At the same time, the nip angle can vary within fairly narrow limits, ensuring the optimality of the crushing process. It was established that the considered option of the fourth-class six-link mechanism geometry has only two folds. An algorithm is presented for searching for assemblies with the purpose of identifying those that are closely adjacent.

Practical value. The results of the conducted research provide the theoretical background and the algorithm for determining the optimal parameters of a two-jaw crusher which can be used at the stage of designing similar crushers. The developed design solution for adjusting the crusher opening expands the scope of application of double-jaw crushers. The obtained dependences of the change in the angle of inclination and the working surface of the jaw over a period make it possible to develop a rational mode of crushing the material

Keywords: *crushing, jaw crusher, lever mechanism, nip angle, six-link mechanism*

Introduction. Almost all jaw crushers which are used nowadays have one movable jaw. Thus, a crushing chamber is formed by three fixed walls and one movable jaw. In crushers with a simple jaw movement, the motion from the crank to the movable jaw is transmitted by a kinematic chain. At the same time, the trajectory of the movable jaw is either straight lines or parts of a circular arc. In crushers with a compound motion of the jaw, the crank and the movable jaw form a kinematic pair. In this case, the trajectory of the particle motion of the movable jaw is closed curves, most often ellipses.

Destructive military actions in Ukraine have resulted in the appearance of a huge amount of construction waste, calculated in millions of tons. Established enterprises do not have sufficient capacity for their complete processing, recovery of marketable product and secondary raw materials, which is one of the reasons for the removal of construction waste to existing waste dumps or landfills that are being created. As a result, thousands of hectares of land are taken out of rational use from agriculture and industry, the ecology deteriorates, the emission of greenhouse gases and hydrogen sulphide increases, and there is a danger of soil and groundwater contamination with harmful chemical compounds.

An extremely pressing problem which has arisen can be partially solved by using mobile and portable crushing and sorting equipment directly on the site of destroyed buildings (a reasonable option) or at special landfills.

The crushing chamber is formed by three fixed walls and one movable jaw. The movement from the crank to the movable jaw is transmitted by a kinematic chain. At the same time, the trajectory of the movable jaw represents parts of the arc of a circle. The material is broken by crushing. The disadvantage characteristic of this class of crushers (short stroke of the jaw and low efficiency of material crushing in the loading zone) is eliminated in a crusher with a compound motion of the jaw, where the crank and the movable jaw form a kinematic pair. In this case, the motion trajectory of the points of the movable jaw is closed curves, most often ellipses. Obtaining the necessary trajectory of the movable jaw has complicated the mathematical model and laborious calculations.

The most complex analytical studies are determined by the design of the crusher with two movable jaws which are in synchronously compound countermotion. The development of new designs, increase in the efficiency of engineering processes and acceleration of the design process require the maximum use of computer technology. Based on this, the synthesis of the mechanism of a two-jaw crusher with a compound motion of the jaws using the Mathcad 15 software product is a relevant task.

Literature review. The first jaw crusher appeared in the middle of the 19^{th} century. That is, people have been using it for over one hundred and fifty years. Despite such a long operation period and the relative simplicity of the design, jaw crushers continue to be studied with the purpose of their further improvement.

Mobile screening and crushing units of high capacity used at the first stage of crushing mainly have jaw crushers with a simple movement of the jaw, and their significant updating in the future is unlikely. The crusher intakes pieces larger than 1 m and has an opening width in the range of 200 mm. Large dimensions and weight prevent its effective use at temporary landfills for the storage of construction waste.

Crushing of material in the second and third stages can be performed by roller, rotary, cone and all other types of jaw crushers. Regarding the use of mobile screening and crushing units, crushers with two movable jaws of compound motion hold a special place. They have advantages in terms of productivity, metal content, crushing action, and the wear-out rate of lining plates. Despite this, double-jaw crushers with upper jaw suspension are currently of limited application. Crushers with a lower jaw support were used in crushing and screening plants but are not currently used. This is associated with the difficulty of adjusting the crusher opening. The lack of a sufficient number of analytical and experimental studies also restrains the development of double jaw crushers. The partial use of research results on jaw crushers with one movable jaw does not solve this problem.

It is well known and is taken for granted that the energy efficiency of grinding equipment is very low, typically less than 10 %. Most of the input power of the process is dissipated as heat, noise and inefficient deformation of the material to be processed and the device itself. In [1], a study is reported to analyse the reasons for such low performance and provides recommendations for improvement. Using a laboratory jaw crusher as a test case, optimization of how to work with the greatest energy efficiency was done using the numerical method of the evolutionary algorithm. For the selected optimized case, an attempt was made to model a jaw crusher using commercial Discrete Element Modelling (DEM) software, after, first, simulating the failure of an individual particle using this software.

In [2], a wide range of the existing compression crushers was studied using the discrete element method. Forecasts are presented for five types of crushers: a jaw crusher, a cone crusher, a gyratory crusher, an impact crusher, and double-roll crusher. The destruction method applied is based on the structure of the particles, taking into account the geometric rules for further generating and assessing the force applied to the particles as they are flowing through the crusher. Based on these simulations, estimates of crusher capacity, product size, productivity, and wear are made.

In the study [3], an analytical perspective is used to develop a fundamental model of a jaw crusher. Previously, jaw crushers were modelled taking into account certain aspects, for example, energy consumption or kinematics. Today, the approaches mainly relate to specific property. In this work, a physical modelling approach was used to derive the modules which are based on the facts regarding crushing machines established from the literature. The modules are divided into kinematics, flow, breakage, capacity, pressure, and power. Each module was obtained and tested separately from other modules to provide increased transparency of the module and its behaviour. The simulation results are presented for the base case of one industrial jaw crusher and compared with manufacturer data.

Another work [4], where the simulation of the operation of the crusher is made on the basis of the discrete element method and verified within the scope of experiments featuring results which agree well. A very good agreement between the measured and predicted results was observed for different sizes of pieces of crushed material. Discrete Element Modelling (DEM) described the performance of the crusher in terms of throughput, product size distribution, compressive force on the surface of the jaws, crushing coefficient, and energy consumption. The authors conclude that DEM can be an excellent tool for predicting crusher performance, including the evaluation of indicators that are difficult to obtain experimentally.

The work [5] reports on the optimization of the design of the movable plate of the jaw crusher. During the crushing process, large and unevenly distributed impact forces occur, which is a consequence of the uneven feed rate and the heterogeneous composition of the material (different hardness). Therefore, the jaw plate experiences a non-uniform distribution of stress, which causes deformation and destruction of the jaws of the crusher. Deformation of the jaw reduces the productivity of the crusher, which results in low efficiency of the crusher, high cost of replacement of crushing plates and higher energy consumption.

The optimization results showed what the optimal design parameters of the jaw should be: thickness, profile, and height. This study suggests that the geometry of the jaw crusher plate affects the flow stress and deformation behaviour during the crushing process. The results of this study are the basis for future designs of jaw crushers for industrial use.

Article [6] analyses the forces acting in a single-jaw crusher, taking into account friction, self-weight, and inertia. The force transmission characteristics can be used as criteria for comparing different designs of the jaw crusher mechanism in order to select the most suitable design for the given application. An equation was obtained which can be used to assess the forces the components of the mechanism sustain.

In work [7], the issue of service reliability of jaw crushers and their components for improving technological capability is considered. This document examines methods of failure analysis of a jaw crusher and its critical components.

In [8], attention is focused on the optimization of energy consumption during the crushing process in the crushing chamber of a single-jaw crusher. Thus, the most acceptable economy technique is the optimization of the parameters of the jaw crusher, such as the crushing coefficient, the frequency of oscillations of the jaw using genetic algorithms and modelling of discrete elements.

In [9], it is emphasized that the efficiency of the jaw crusher primarily depends on the kinematic characteristics of the rotary jaw during crushing. This research work is devoted to the kinematic analysis of the jaw of a single-jaw crusher. During the analysis, the system is considered as a four-link crank-and-slot mechanism. Through this analysis, the geometry of the crushing chamber can be optimized according to the crushing motion requirements in different areas of the crushing chamber.

In [10], a method for predicting the specific energy consumption of a jaw crusher based on an adaptive neuro-fuzzy interference system (ANFIS) is proposed. In addition to the power required to crush the rock, the conducted research included optimization of the crushing process so as to reduce this estimated power. The results showed the effectiveness of the model in exact prediction of the crushing power with an accuracy of more than 96 % compared to the corresponding actual data.

In [11], four variants of forms of crushing chambers of jaw crushers are considered. Based on the research, it is concluded that the curved crushing chamber has better performance indicators.

It is shown in [12] that the energy consumption of a jaw crusher depends on the average diameter of the pieces of material entering the crusher and the width of the outlet opening. In addition, energy consumption is affected by the frequency of oscillations of the movable jaw.

In [13], the purpose of the study was to develop an automated system for controlling the operation of a jaw crusher as a solution to real tasks for more efficient production of crushed stone. A cost analysis was performed to study the impact of the proposed system on the cost and time of the production process. The results confirmed the fact that the proposed system improves the operation of the crusher. Automatic crusher control increases net profit and feed rate while reducing end product waste.

In [14], the issue of choosing a suitable material to manufacture jaws, which would well resist tearing, shear and impact stress, was considered. The study showed that AISI 9255 low-alloyed steel maximizes productivity and minimizes the cost of the crusher.

Analysing the works of the last decade, we can conclude that theoretical and experimental studies on crushers are conducted using modern methods and the best computer products, which is generally typical for works in the mining industry. Numerical calculations are performed taking into account the finite element method [15], mathematical models are obtained using the discrete element method [16]. Theoretical studies are conducted giving due consideration to the specifics of the industry [17, 18].

A fundamentally new solution is the formation of a crushing chamber with two movable jaws with a compound motion based on a mechanism with a closed lever circuit. According to Assur classification, such mechanisms belong to the fourth class. In 2019, the authors of this paper proposed to use a closed circuit of a similar lever mechanism as a crushing chamber. This article develops ideas presented by the authors in 2019.

Purpose. The purpose of this work is the synthesis of the mechanism of a two-jaw crusher with a compound motion of the jaws based on a lever mechanism of the fourth class, which ensures a high-quality crushing process and a change in the angle of gripping pieces of material in the range of 18–20°. This will contribute to a more accurate determination of the rational values of the structural and kinematic parameters of the crusher for specific structural designs and operating conditions.

To gain the purpose, it is necessary to carry out a theoretical study on the link mechanism of the crusher.

Methods. To study the mechanism of a two-jaw crusher with a compound motion of the jaws based on a fourth-class lever mechanism, the analytical method of analysis using the Mathcad 15 program was chosen.

Results. Research on jaw crushers is conducted in two directions. The first is the improvement of the crusher design itself, the second one is the enhancement of physical and organizational factors affecting the crushing process. Moreover, the second direction is based on the relevant modern software products.

The design of the crusher (Fig. 1) with two movable jaws of complex motion, improved by the authors, contains a housing *1* in which movable jaws *3* and *4* are installed with the help of the lower eccentric support *2*.

The eccentric shafts of the supports *2* are driven by the electric motor by means of a V-belt transmission and are synchronized by a gear transmission, which forms their counterrotation (not shown in the figure).

The advantage of the lower jaw support is the fact that they ensure secure crushing of material with fractions no larger than the set width of the crusher opening.

Each jaw in its upper part is connected to the housing with the help of toggle plates *5*. The necessary contact between the movable jaw and the toggle plate is provided by a thrust with an elastic element *6*.

During the operation of the crusher, the raw material is fed into the crushing chamber formed by the working surfaces of the jaws and the side walls of the crusher housing. During the rotation of the eccentric shafts, the movable jaws move synchronously in the vertical plane, and due to inclined toggle plates, their countermotion is carried out. In the process of downward movement of the jaws, their working surfaces converge, and the material is crushed; when the jaws move upward, the crushed product is unloaded.

The destruction of pieces of material occurs according to the principle of crushing. By forcing the crushed material out of the crusher opening (friction force is directed downwards), compound rocking jaw crushers feature higher performance than simple rocking jaw crushers. Eliminating the relative displacement of the crushing jaws in the vertical direction significantly reduces the wear of the crushing plates.

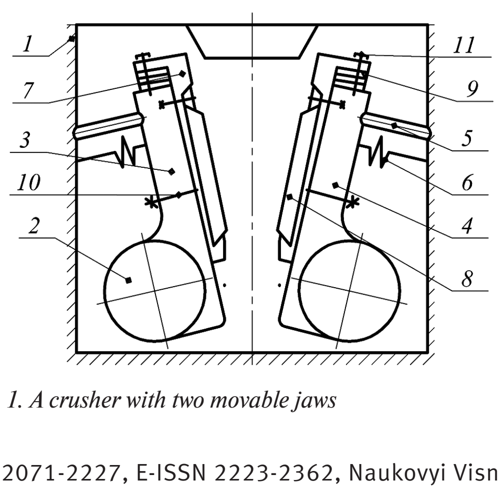

Fig. 1. A crusher with two movable jaws

The adjustment of the width of the crusher opening is carried out using a new structural unit, which is a movable block consisting of a foundation plate *7*, a lining plate *8*, measuring control blades *9*, clamping elements *10, 11.*

To change the size of the crusher opening, loosen the bolted connections of the foundation plate of the movable block to the jaw housing. With the help of a threaded connection of pins *11*, the block moves along the adjacent surface of the jaw housing. Depending on the direction of movement of the block, the width of the crusher opening increases or decreases. The required width of the crusher opening is provided by a set of measuring blades, whose thickness is functionally related to the movement of the working surface of the jaw horizontally. After installing the measuring blades, the movable blocks are fixed with fasteners and the crusher is ready to work with the new required width of the crusher opening. At the same time, the nip angle remains unchanged. Assembling and disassembling of lining plates are performed by completely removing the movable block, which ensures convenience and rate of maintenance. This constructive solution removes one of the main obstacles to the use of crushers with two movable jaws at crushing and screening plants, but new analytical studies are still required.

A mechanism with a closed lever circuit was chosen as the framework for the crusher. These mechanisms, as is known, belong to the fourth class according to Assur classification. The diagram of this mechanism is shown in Fig. 2. The power-operated crank *1* rotates relative to the rack 0, which provokes the movement of a three-hinged link *2*. Links *3* and *4* are presented as two jaws between which material is crushed. The CDEF contour, thus, forms a crushing chamber. The second three-hinged link *5* oscillates relative to the rack *0*.

The theoretical study on this problem is very convenient to perform either using the Matlab program or the Mathcad program. The authors preferred the Mathcad 15 software. As a result of the preliminary geometric analysis of the lever mechanism, the following geometric parameters (length in m) were accepted for the research (henceforward, the mathematical calculations are presented as screenshots of the corresponding program fragments in Mathcad 15).

$x_A := 0 \quad y_A := 0 \quad x_G := 0.5 \quad y_G := 1.3 \quad l_1 := 0.1$

$l_2 := 0.11 \quad l_{21} := 0.22 \quad l_3 := 1.4 \quad l_4 := 1.4$

$l_5 := 0.8 \quad l_{51} := 0.3 \quad \beta := 34deg \quad \alpha := 36.336deg$

The links of the mechanism were replaced by vectors, as shown in Fig. 3.

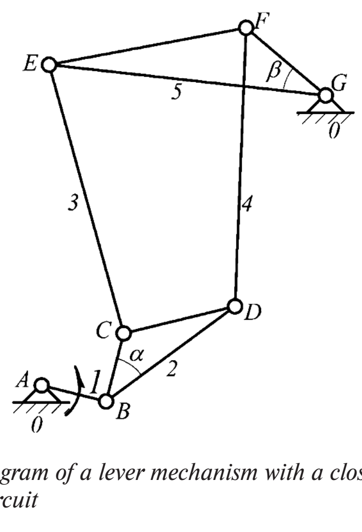

Fig. 2. Diagram of a lever mechanism with a closed quadrilateral circuit

The interval AG was represented by the vector l_0 with the following parameters

$$l_0 := \sqrt{(x_G - x_A)^2 + (y_G - y_A)^2} \quad \phi_0 := \operatorname{atan}\left(\frac{y_G - y_A}{x_G - x_A}\right)$$

$$l_0 = 1.3928 \quad \phi_0 = 68.962 \cdot \text{deg} \quad .$$

The vectors were presented in the following form

$$l_1(\phi_1) := l_1 \cdot \begin{pmatrix} \cos(\phi_1) \\ \sin(\phi_1) \\ 0 \end{pmatrix} \quad l_2(\phi_2) := l_2 \cdot \begin{pmatrix} \cos(\phi_2) \\ \sin(\phi_2) \\ 0 \end{pmatrix} \quad l_3(\phi_3) := l_3 \cdot \begin{pmatrix} \cos(\phi_3) \\ \sin(\phi_3) \\ 0 \end{pmatrix}$$

$$l_{21}(\phi_2) := l_{21} \cdot \begin{pmatrix} \cos(\phi_2 - \alpha) \\ \sin(\phi_2 - \alpha) \\ 0 \end{pmatrix} \quad l_4(\phi_4) := l_4 \cdot \begin{pmatrix} \cos(\phi_4) \\ \sin(\phi_4) \\ 0 \end{pmatrix} \quad l_5(\phi_5) := l_5 \cdot \begin{pmatrix} \cos(\phi_5) \\ \sin(\phi_5) \\ 0 \end{pmatrix}$$

$$l_{51}(\phi_5) := l_{51} \cdot \begin{pmatrix} \cos(\phi_5 - \beta) \\ \sin(\phi_5 - \beta) \\ 0 \end{pmatrix} \quad l_0(\phi_0) := l_0 \cdot \begin{pmatrix} \cos(\phi_0) \\ \sin(\phi_0) \\ 0 \end{pmatrix} .$$

To determine the consecutive positions of the links of the mechanism, two vector equations were composed

$$l_1(\phi_1) + l_2(\phi_2) + l_3(\phi_3) = l_0(\phi_0) + l_5(\phi_5)$$

$$l_1(\phi_1) + l_{21}(\phi_2) + l_4(\phi_4) = l_0(\phi_0) + l_{51}(\phi_5)$$

Further, with the help of a Given-Find block, the solution of this system of vector equations was obtained for eight consecutive values of the rotation angle of the crank 1, given by the formula

$$\phi_1 := \frac{\pi}{4} \cdot (n - 1)$$

By varying π from 1 to 9, we obtained the crank angles from 0 to 360° every other 45°. Fig. 4 shows a fragment of the Given-Find block for the angle of the crank rotation $\phi_1 = 90°$.

A similar solution for the crank angle $\phi_1 = 180°$ looks as follows (Fig. 5).

According to the results of this solution, consecutive positions of the closed circuit of the links forming the crushing chamber were constructed (Fig. 6). The first position corresponds to the crank angle $\phi_1 = 0°$. The arrows indicate the direction of vertical displacement of the lower points of the jaws 3 and 4.

The relative position of the jaws was studied in order to determine the angle of gripping the material ($\Delta\phi = \phi_3 - \phi_4$). Fig. 7 shows the dependence of the nip angle on the crank angle.

The nip angle varies from 17.68 to 18.78°, i.e. the maximum difference is 1.1°. The change in the angle of gripping the material in one revolution of the driving crank is shown in Tables 1 and 2.

Of interest is the change in the relative position of the jaws, which determines the immediate destruction of pieces of material between them. Fig. 8 shows graphs of changes in the distance between the upper and lower points of both jaws.

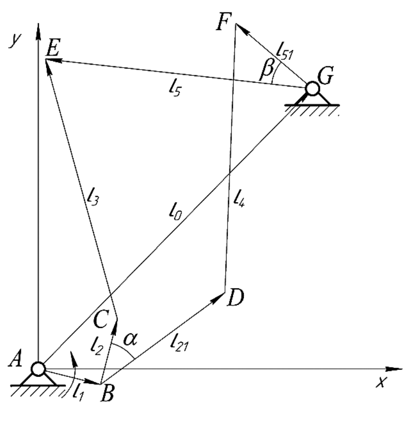

Fig. 3. Vector diagram of the lever mechanism

$$\phi_1 = 90 \cdot \text{deg} \quad \phi_2 := 1 \quad \phi_3 := 1.5 \quad \phi_4 := 1.5 \quad \phi_5 := 3$$

Given

$$l_1(\phi_1) + l_2(\phi_2) + l_3(\phi_3) = l_0(\phi_0) + l_5(\phi_5)$$

$$l_1(\phi_1) + l_{21}(\phi_2) + l_4(\phi_4) = l_0(\phi_0) + l_{51}(\phi_5)$$

$$\begin{pmatrix} \phi_2 & \phi_3 \\ \phi_4 & \phi_5 \end{pmatrix} := \text{Find}(\phi_2, \phi_4, \phi_3, \phi_5) \quad \begin{pmatrix} \phi_2 & \phi_3 \\ \phi_4 & \phi_5 \end{pmatrix} = \begin{pmatrix} 46.08 & 104.07 \\ 86.09 & 162.75 \end{pmatrix} \text{deg} .$$

Fig. 4. An example of solving simultaneous vector equations

$$\phi_1 = 180 \cdot \text{deg} \quad \phi_2 := 1 \quad \phi_3 := 1.5 \quad \phi_4 := 1.5 \quad \phi_5 := 3$$

Given

$$l_1(\phi_1) + l_2(\phi_2) + l_3(\phi_3) = l_0(\phi_0) + l_5(\phi_5)$$

$$l_1(\phi_1) + l_{21}(\phi_2) + l_4(\phi_4) = l_0(\phi_0) + l_{51}(\phi_5)$$

$$\begin{pmatrix} \phi_2 & \phi_3 \\ \phi_4 & \phi_5 \end{pmatrix} := \text{Find}(\phi_2, \phi_4, \phi_3, \phi_5) \quad \begin{pmatrix} \phi_2 & \phi_3 \\ \phi_4 & \phi_5 \end{pmatrix} = \begin{pmatrix} 76.44 & 98.31 \\ 80.52 & 166.1 \end{pmatrix} \text{deg}$$

Fig. 5. An example of solving simultaneous vector equations

It is easily seen that the feed opening length changes slightly within 0.565–0.575 m. The length between the lower points of the outlet hole changes significantly from 0.11 to 0.15 m, ensuring the required crushing of pieces of material.

Previously, the authors performed theoretical studies on the use of fourth-class lever mechanisms in crushers. It is shown that during the operation of these heavy machines, contingency situations may arise, related to the close location of two different assemblies of the mechanism. In the general case, the number of possible assemblies of this mechanism of the fourth class is four. This mechanism being used for a crusher, the number of assemblies is reduced to two. But even two assemblies can be located very close.

To find possible combinations of the mechanism, vector equations of closedness are written down, for example, for two circuits BCEGB and BDFGB. From these equations, the dependences of the angles ϕ_5 and ϕ_{51} on the angle ϕ_2 are obtained. We find the intersection points of the graphs of these dependencies, whose coordinates will be variants of possible additions.

For example, Fig. 9 shows two combinations of the considered mechanism for the angle $\phi_1 = 135°$. These assemblies

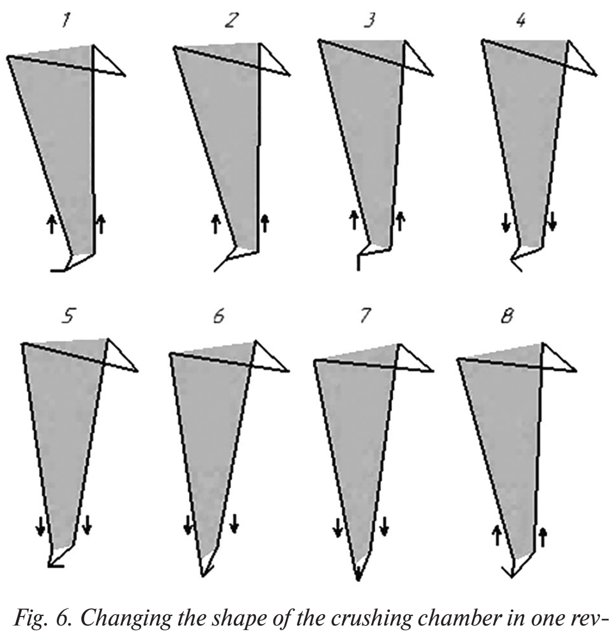

Fig. 6. Changing the shape of the crushing chamber in one revolution of the power-operated crank

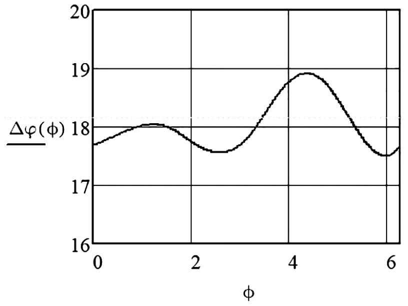

Fig. 7. Change in the nip angle (in degrees) in one rotation of the crank (radian)

Table 1

Change in the angle of gripping the material in one revolution of the driving crank from 0 to 135°

ϕ_1°	0	45	90	135
ϕ_3°	108.1	107.4	104.1	100.4
ϕ_4°	90.44	89.43	86.09	82.75
$\lvert\phi_3 - \phi_4\rvert^\circ$	17.68	17.96	17.98	17.70

Table 2

Change in the angle of gripping the material in one revolution of the driving crank from 180 to 315°

ϕ_1°	180	225	270	315
ϕ_3°	98.30	98.20	101.0	105.5
ϕ_4°	80.52	79.49	82.25	87.71
$\lvert\phi_3 - \phi_4\rvert^\circ$	17.79	18.70	18.78	17.82

are not very close, but in general, it is necessary to make a detailed analysis of this issue.

This factor must be considered when designing such machines. The frictional work in kinematic pairs of these machines is very significant, which must also be taken into account. The influence of dynamic factors is insignificant and can be ignored. It is possible to separate the assembly from one another by changing the geometric parameters of the mechanism (length of the links); however, this possibility is very limited, since the geometry of the mechanism is mainly determined by technological requirements.

Another way is to reposition the drive of the mechanism, i.e. the rotational centre of the crank and its length. In order to follow this path, it is necessary to formulate the conditions for the existence of a crank for a fourth-class mechanism. The rule is known, established by the German mechanical engineer Franz Grashof at the end of the *19th* century, about the condition for the existence of a crank for an articulated four-link unit. Such conditions are not established for more complex mechanisms (third, fourth, etc. classes).

In 2018, the authors in the work "Some aspects of synthesis of linkage of complex structures" showed that lever mechanisms of the fourth class can have several assemblies. Sometimes the assemblies are located close together, which can result in an accident in heavily loaded devices. Therefore, this should be taken into account at the stage of designing such crushers. Thus, this crusher also has close assemblies, so the structure must be strong to avoid accidental transition from one assembly to another under the action of high efforts.

Conclusions. The review and analysis of literary sources showed that one of the main obstacles to the widespread use of a crusher with two movable jaws and the lower placement of an eccentric support is the significant complexity of installing and adjusting the crusher opening.

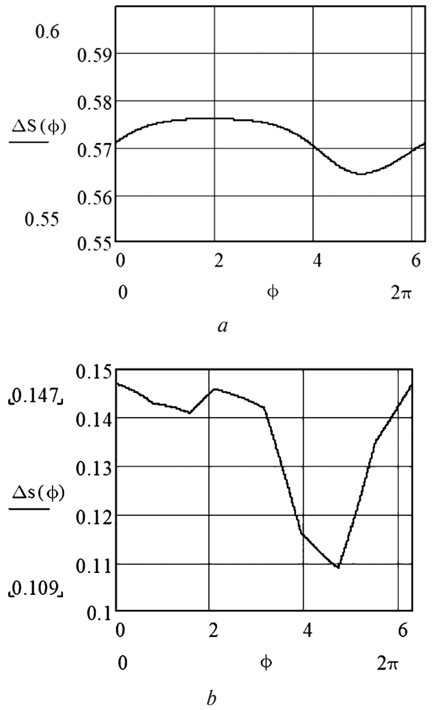

Fig. 8. Horizontal distance (in meters):

a — between the upper points of the jaws; b — between the lower points of the jaws

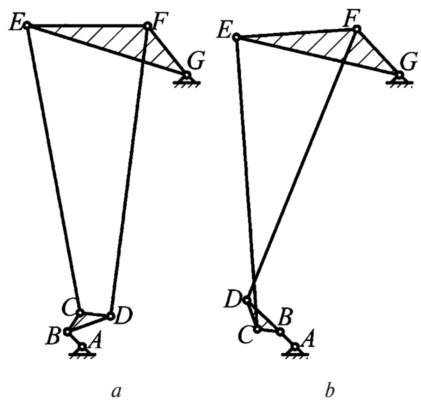

Fig. 9. Assemblies of the crusher mechanism for the angle $\phi_1 = 135°$

a — assembly 1; b — assembly 2

A large volume of scientific research concerns jaw crushers with a single movable jaw. Some of the results may be directly, or with minor modifications, adapted for double-jaw crushers, and a significant increase in research focusing directly on jaw crushers with two movable jaws is required.

A new constructive solution of the mechanism for adjusting the crusher opening with two movable jaws and the lower attachment of eccentric shafts eliminates one of the main obstacles to their use in crushing and screening plants.

The obtained dependences of the change in the angle of inclination and the movement of the working surface of the jaw over a period are the basis for the development of the technological mode of the crushing process.

Based on the theoretical analysis of the lever mechanism of the two-jaw crusher, performed in the Mathcad-15 software, optimal geometric parameters of the mechanism were obtained, which ensure a change in the nip angle of the material in the range of 18–20°. This range of nip angle changes minimizes the energy consumed for crushing.

The work in this direction should be continued with the purpose of developing a programme for the synthesis of geometrical parameters of the mechanism at a given value of the range of change in the angle of gripping material.

References.

1. Holmberg, K., Kivikytö-Reponen, P., Härkisaari, P., Valtonen, K., & Erdemir, A. (2017). Global energy consumption due to friction and wear in the mining industry. *Tribology International, 115*(6), 116-139. https://doi.org/10.1016/j.triboint.2017.05.010.

2. Cleary, P. W., & Sinnott, M. D. (2015). Simulation of particle flows and breakage in crushers using DEM: Part 1–Compression crushers. *Minerals Engineering, 74*, 178-197. https://doi.org/10.1016/j.mineng.2014.10.021.

3. Johansson, M., Bengtsson, M., Evertsson, M., & Hulthén, E. (2017). A fundamental model of an industrial-scale jaw crusher. *Minerals Engineering, 105*, 69-78. https://doi.org/10.1016/j.mineng.2017.01.012.

4. Barrios, G. K., Jiménez-Herrera, N., Fuentes-Torres, S. N., & Tavares, L. M. (2020). DEM simulation of laboratory-scale jaw crushing of a gold-bearing ore using a particle replacement model. *Minerals, 10*(8), 717. https://doi.org/10.3390/min10080717.

5. Murithi, M., Keraita, J. N., Obiko, J. O., Mwema, F. M., Wambua, J. M., & Jen, T. C. (2022). Optimisation of the swinging jaw design for a single toggle jaw crusher using finite element analysis. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 1-8. https://doi.org/10.1007/s12008-022-01044-3.

6. Oduori, M. F., Munyasi, D. M., & Mutuli, S. M. (2016). Analysis of the single toggle jaw crusher force transmission characteristics. *Journal of Engineering*, 1-9. https://doi.org/10.1155/2016/1578342.

7. Sinha, R. S., & Mukhopadhyay, A. K. (2016). Failure analysis of jaw crusher and its components using ANOVA. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 38*, 665-678. https://doi.org/10.1007/s40430-015-0393-6.

8. Mwangi, P. N. U., Muvengei, O. M., & Mbuya, T. O. (2022, March). Review of discrete element modelling in optimisation of energy consumption of a single-toggle jaw crusher. *In Proceedings of the Sustainable Research and Innovation Conference*, 251-259. https://doi.org/10.3926/jiem.3606.

9. Deepak, B. B. V. L., & Bahubalendruni, M. R. (2017). Numerical analysis for force distribution along the swing jaw plate of a single toggle jaw crusher. *World Journal of Engineering, 14*(3), 255-260. https://doi.org/10.1108/WJE-07-2016-0025.

10. Abuhasel, K. A. (2019). A comparative study of regression model and the adaptive neuro-fuzzy conjecture systems for predicting energy consumption for jaw crusher. *Applied Sciences, 9*(18), 3916. https://doi.org/10.3390/app9183916.

11. Zhong, X., Niu, X., Ji, Q., & Shen, X. (2020, September). Simulation Analysis of Cavity Shape of Compound Pendulum Jaw Crusher. In *Journal of Physics: Conference Series, 1637*(1), 012130. IOP Publishing. https://doi.org/10.1088/1742-6596/1622/1/012023.

12. Hristova, T., Yanev, A., & Savov, N. (2018). Determination of the influence of jaw movement frequency of jaw crusher on energy consumption. *Annals of the University of Petrosani-Electrical Engineering, 20,* 1454-8518. Retrieved from https://www.upet.ro/annals/electrical/doc/2018/Annals%20Electric%202018%20v1.pdf.

13. Elgendi, E. O., & Shawki, K. (2021, December). Automated process control system of Jaw crusher production. In *Journal of Physics: Conference Series, 2128*(1), 012034. IOP Publishing. https://doi.org/10.1088/1742-6596/2128/1/012034.

14. Adetunji, A. R., Abioye, A. A., Isadare, D. A., & Akinluwade, K. J. (2015). Material Selection for Crusher Jaw in a Jaw Crusher Equipment. *International Journal of Materials Engineering, 5*(2), 17-22. https://doi.org/10.5923/j.ijme.20150502.01.

15. Samorodov, V., Bondarenko, A., Taran, I., & Klymenko, I. (2020). Power flows in a hydrostatic-mechanical transmission of a mining locomotive during the braking process. *Transport problems, 15,* 17-28. https://doi.org/10.21307/tp-2020-030.

16. Taran, I., & Klymenko, I. (2017). Analysis of hydrostatic mechanical transmission efficiency in the process of wheeled vehicle braking. *Transport problems, 12,* 45-56. https://doi.org/10.20858/tp.12.se.4.

17. Kravets, V., Samusia, V., Kolosov, D., Bas, K., & Onyshchenko, S. (2020). Discrete mathematical model of travelling wave of conveyor transport. *II International Conference Essays of Mining Science and Practic, 168*, 00030. https://doi.org/10.1051/e3sconf/202016800030.

18. Haddad, J. S., Denyshchenko, O., Kolosov, D., Bartashevskyi, S., Rastsvietaiev, V., & Cherniaiev, O. (2021). Reducing Wear of the Mine Ropeways Components Basing Upon the Studies of Their Contact Interaction. *Archives of Mining Sciences, 66*(4), 579-594. https://doi.org/10.24425/ams.2021.139598.

Обґрунтування раціональних параметрів проєктування дробарної машини з двома рухомими щоками

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Мета. Розробка конструкції механізму дробильної двощокової машини зі складним рухом щок, що забезпечує зміну кута захоплення шматків матеріалу в дуже невеликому діапазоні.

Методика. У роботі виконане теоретичне дослідження важільного механізму четвертого класу, як основи двощокової дробарки, за допомогою програмного продукту Mathcad 15. Дослідження виконано на векторному поданні ланок шарнірного механізму. Розробка та аналіз конструктивних рішень виконувалася з використанням програмного продукту Autocad, що знижує ризик помилок і підвищує якість процесу проєктування.

Результати. У роботі теоретично визначені раціональні геометричні параметри двощокової дробарної машини з оптимальним значенням кута захоплення, камера дроблення якої сформована замкненим контуром плоского важільного механізму четвертого класу та запропоновано нове конструктивне рішення механізму регулювання розвантажувальної щілини дробарки із двома рухомими щоками й нижнім кріпленням ексцентрикових вузлів. Розроблений пристрій у вигляді окремих блоків виконано із можливістю їх простого монтажу та демонтажу, що забезпечує швидкість і якість заміни футерувальних плит або наплавочного відновлення зношеної робочої поверхні щок. Відносний рух щок забезпечує дроблення кусків матеріалу із потрібним коефіцієнтом дроблення. Геометричні параметри отримані методом кінематичного синтезу. Теоретично визначені раціональні геометричні параметри камери дроблення двощокової дробарки, отримані залежності зміни кута захвату за висотою рухомої щоки за період руху та зміни ходу стиснення, що забезпечує силову взаємодію робочої поверхні щок із матеріалом.

Наукова новизна. Доведено, що чотирикутний замкнений контур важільного механізму четвертого класу може бути використаний як дробарна камера двощокової дробарки. Дві ланки замкненого контуру виконують функції щок, що руйнують куски матеріалу. При цьому кут захоплення може змінюватися в невеликих межах, забезпечуючи оптимальність процесу дроблення. Встановлено, що розглянутий варіант геометрії шестиланкового механізму четвертого класу має тільки два складення. Наведено алгоритм пошуку складань з метою виявлення таких, що близько розташовані.

Практична значимість. Результати проведених у роботі досліджень дають теоретичне підґрунтя та алгоритм визначення оптимальних параметрів двощокової дробарки, що можуть бути використані на стадії проєктування подібних дробарних машин. Розроблене конструктивне рішення регулювання розвантажувальної щілини розширює сферу застосування двощокових дробарок. Отримані залежності зміни кута нахилу й перебігу робочої поверхні щоки за період дозволяють розробляти раціональний режим дроблення матеріалу.

Ключові слова: *дроблення, щокова дробарка, важільний механізм, кут захоплення, шестиланковий механізм*

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