UDC 621.926.2
DOI: https://doi.org/10.32347/tb.2024-41.0403

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STRUCTURAL REVIEW AND ASSESSMENT OF TECHNOLOGICAL AND DESIGN PARAMETERS OF CRUSHING EQUIPMENT FOR THE CONSTRUCTION INDUSTRY

ABSTRACT. *Due to the growth in the volume of mineral extraction and the increasing demand for the processing of construction waste, reducing energy consumption has become one of the key areas of research in the field of machines for the production of building materials. Solving the problem of determining energy consumption is a difficult task, since these costs depend on numerous variable factors that vary during the operation of the machine and are difficult to accurately predict. The development and creation of energy-efficient crushing machines is one of the areas of improving the technologies for the production of building materials. The work considers the designs of common crushing machines for the production of building materials and their features. A criterion-based assessment was performed on the main generalized parameters of the mechanical mode, on the basis of which the most promising models were established and recommendations were given regarding the area of further research.*

Keywords: *crusher, energy efficiency, criterial assessment, mechanical mode parameters.*

1. Introduction. The process of disintegration (division into particles) of a material is understood as a series of operations as a result of which the size of a solid particle of material (rock) is reduced from the initial to the final sizes required for the industry. For example, for the construction industry, the size of the raw material can reach 1.2 meters in diameter, while the size of the finished product can reach several microns in diameter. The process of disintegration in the construction materials industry can be divided into two separate processes: crushing and grinding [1],[2].

It has been established that a significant amount of energy is spent on crushing and grinding various materials. These costs continue to grow due to the increase in the volume of mineral extraction and the growing need for processing construction waste. In addition to energy costs, the operating costs of enterprises engaged in the production of construction materials are significant [3], [4].

Thus, the problem of reducing the cost of manufactured products is relevant today. Optimization of energy consumption of the crushing process is a rather difficult task, as it is associated with a significant number of factors. In general, all factors that affect the energy consumption of the crushing process can be divided into two categories: 1) physical properties of the working environment; 2) technological and design features of crushing equipment [5].

Common crushing equipment used in most enterprises for the production and processing of building materials are jaw, cone, roller, rotary and hammer crushers [6],[7].

2. Literature Review and Problem Formulation. In [8], methods for analyzing the failure of jaw crusher structural elements using statistical methods are considered, but the paper does not specify which jaw crusher model is used for the analysis, which could give an idea of the physical characteristics of the materials from which the crusher elements are made. In addition, it is not clear whether these methods can be used for other crushing machines and, if so, what parameters need to be generalized. In [9], a good energy analysis of the basic laws of material destruction by the working bodies of crushing machines is given, but the work poorly highlights the design features of crushing machines and, in general, the emphasis is on the physical characteristics of the working environment and the parameters of the mechanical mode, but the dependence of these parameters on the design features of crushing machines is not noted. In [10], the crushing process by a jaw crusher is compared from the point of view of energy consumption when using a single-stage and two-stage scheme. In this case, an experimental jaw crusher is used in the paper, i.e., to use the results of the work, it will be necessary to use similarity coefficients. On the other hand, these results can only be used for jaw crushers with simple jaw movement.

3.Research Objectives. To analyze modern designs of crushing equipment and determine the main directions of their improvement. Based on the analysis, to establish a set of parameters of the mechanical mode of crushers that have the greatest impact on energy consumption. To assess the impact of crusher design elements on the consumption of supplied energy.

4. Materials and methods. The main materials for the analysis are scientific, technical and reference literature on domestic and foreign samples of modern crushing equipment. The main methods used in the work are criterion-based evaluation of parameters based on the construction of histograms of the corresponding criteria. Microsoft Excel software is used to perform calculations and construct histograms.

5. Discussion of the results. Jaw crushers are divided into the following types by the nature of their operation, which depends on the shape of the crushing parts and their movement: 1) jaw crushers with a simple jaw movement (double toggle jaw crusher); 2) jaw crushers with a complex jaw movement (single toggle jaw crusher). A separate subgroup should be allocated to the vibrating jaw crusher. This classification, in addition to the vibrating jaw crusher, is classical. However, today there is a trend towards the creation of compact, modular and mobile equipment. Because of this, the jaw crusher with a complex jaw movement has become more widespread [11].

Jaw crushers are mainly used for coarse and medium crushing. Since the shape of the crushing chamber of jaw crushers is wedge-shaped, when the material to be crushed enters it, it is destroyed due to the convergence of the crushing cheeks. The main method of destruction in jaw crushers is destruction by crushing, however, due to the kinematic features of the movement of the cheek and the geometry of the crushing surface in the crushing chamber, it was possible to combine other methods of destruction. Such methods are destruction by abrasion and splitting or bending. The combination of abrasion and splitting was implemented in crushers with complex movement of the cheek [12], [13].

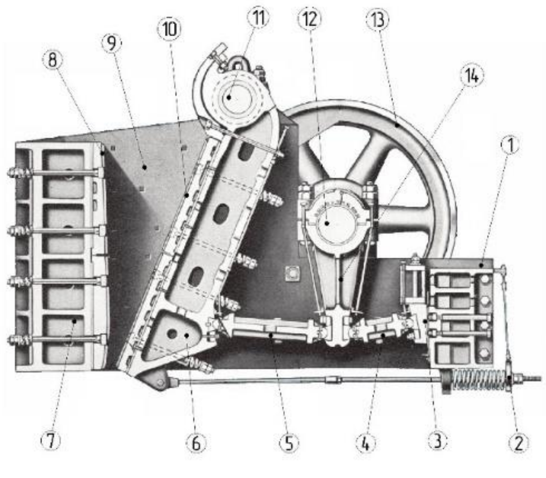

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Fig. 1. Jaw crusher with simple jaw movement:
a – jaw crusher with simple jaw movement of the Terex D60 Jaques company;
b – jaw crusher with simple jaw movement in section: 1 – housing; 2 – rod; 3 – adjustment mechanism; 4, 5 – spacer plate; 6 – movable jaw; 7 – fixed jaw; 8, 10 – replaceable crushing plate; 9 crushing chamber; 11 – axis; 12 – eccentric shaft; 13 – flywheel; 14 - connecting rod

A jaw crusher with a simple jaw movement is shown in Fig. 1. The structure of a jaw crusher with a simple jaw movement is shown in Fig. 1, b. The crusher consists of a housing 1 in which an eccentric shaft 12 is mounted on bearings with a connecting rod 14 suspended from it. The lower end of the connecting rod has special sockets in which the spacer plates 4 and 5 are freely installed. The spacer plate 5 rests with its other side against the socket of the movable jaw 6. The other end of the spacer plate 4 rests against the adjusting mechanism - a wedge stop. The rod 2 provides the reverse movement of the movable jaw and ensures reliable fixation of the spacer plates. The movable jaw is suspended on an axis 11, which is installed in the crusher housing. The grinding plates 8 and 10 are fixed to the stationary 7 and movable 6 jaws, respectively [14]. The working surfaces of the crushing plates and the side walls of the crusher body form a crushing chamber 9. On one side, a belt pulley is installed on the cantilever part of the eccentric shaft, through which the crusher is driven by the electric motor. On the other side, a flywheel is installed on the cantilever part of the eccentric shaft.

The main functions of the flywheel are to ensure smooth running during the work process and alternate energy storage and transmission. Fig. 1, a shows a model of a jaw crusher with a simple jaw movement D60, manufactured by Terex.

A jaw crusher with a complex jaw movement is shown in Fig. 2.

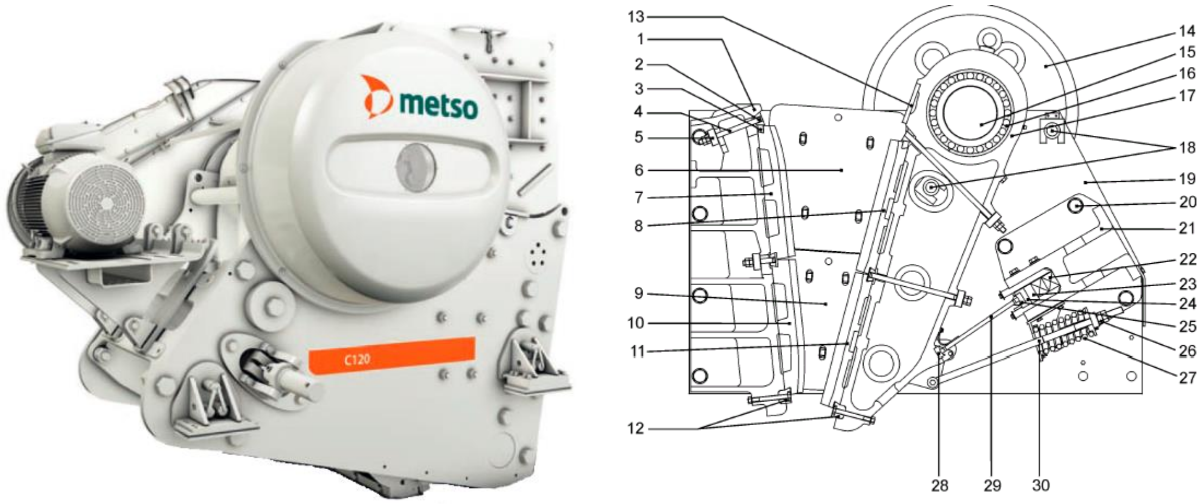

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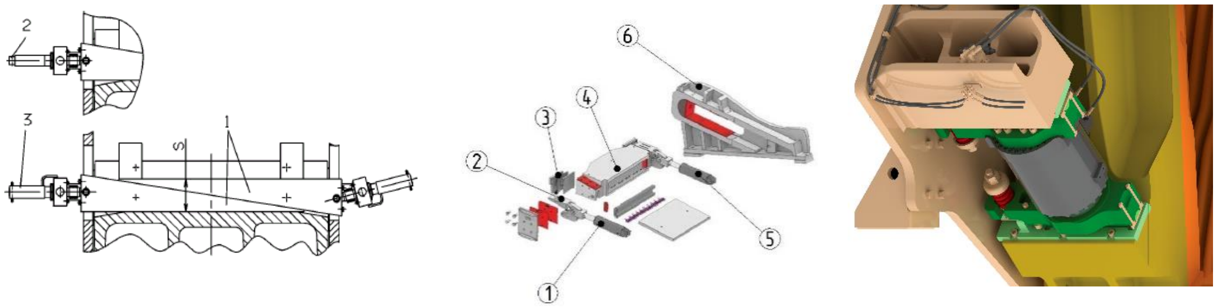
Fig. 2. Jaw crusher with complex jaw movement:

a – jaw crusher with complex jaw movement C120 of Metso; b – jaw crusher with complex jaw movement in section: 1 – front section of the frame; 2 – upper wedge; 3 – filling wedge; 4 – jaw plate bolt; 6 - disc spring assembly; 6 – side lining plate of the crushing chamber, upper; 7 – stationary jaw plate, upper; 8 - movable jaw plate, upper; 9 - side lining plate of the crushing chamber, lower; 10 - stationary jaw plate, lower; 11 - movable jaw plate, lower; 12 – fixed wedge; 13 - movable jaw eyelet protection plate; 14 – flywheel; 15 – eccentric shaft; 16 – movable cheek bearing; 17 – movable cheek; 18 – frame fastening rods; 19 – side plate; 20 – frame bolt; 21 – rear frame section; 22 – adjusting wedges; 23 – insert; 24 – plate of support liners of the spacer plate; 25 – spacer plate liner; 26 – locknuts with thrust bearing; 27 – cheek withdrawal (tension) spring; 28 – spacer plate liner; 29 – spacer plate; 30 – cheek withdrawal rod.

The structure of a jaw crusher with a complex jaw movement is similar to that of a crusher with a simple jaw movement. The difference is that the crusher with a complex jaw movement does not have a connecting rod, and the movable jaw 17 is fixed directly to the eccentric part of the drive shaft 15. In the lower part, the jaw is connected by a spacer plate 29 to the machine hub through a wedge adjustment mechanism 22. The crusher also has a jaw withdrawal rod 30 [15]. In such a crusher, the trajectory of the swing of the movable jaw is a closed elliptical curve, with a minimum difference between the axes of the ellipse in the upper part of the jaw and a maximum in the lower part. Changing the nature of the swing of the movable jaw changes the load pattern on the material, which is destroyed under the action of compressive and shear loads.

In modern models of jaw crushers, automated work process control systems are widely implemented. One of such systems is automatic adjustment of the outlet opening due to the hydraulic system of driving the adjusting wedges or directly using hydraulic cylinders. The main components of the mechanical system of adjusting the outlet opening (Fig. 3) are adjusting wedges 1, nuts 2 and stop tubes 3. To change the outlet opening of the crusher, it is necessary to turn the stop nuts 3 using a separate ratchet mechanism.

On Fig. 3, b shows the hydraulic system for moving the spacer plate of a jaw crusher. In crushers with such a system, the outlet opening is changed by moving the wedge stops 2, hydraulic cylinders 1 and 5. In turn, the wedge stops move the spacer plate 4. The position of the plate is fixed in the housing 6 by means of plates 3.



a b c

Fig. 3. Adjusting devices of the jaw:

a – adjustment of the outlet opening by turning the nut with a ratchet mechanism; b – adjustment of the outlet opening by moving the spacer plate with hydraulic cylinders; c – adjustment of the outlet opening by moving the hydraulic cylinder rod

Fig. 3, c shows the outlet adjustment unit of a jaw crusher. In such crushers, the spacer plate and the adjustment device are replaced by a hydraulic cylinder.

The main parameters of the mechanical mode of jaw crushers are: 1) the angle of engagement; 2) the stroke of the movable jaw; 3) the frequency of the drive shaft; 4) productivity; 5) power.

The most famous manufacturers of jaw crushers are the following companies: Metso, Sandvik, Telsmith, Terex, Lipmann- Milwaukee, Thyssenkrupp, Eagle, Parker, Meka, FTM, Trio, Hewitt Robins, etc. It is also worth mentioning such manufacturers as Komatsu, Finlay, McClouskey, Rubble Master, Tesab, however, they are more inclined to manufacture mobile crushing plants, which include jaw crushers.

When considering the parameters of the mechanical mode, the following main criteria of influence for jaw crushers were determined: 1) productivity per mass; 2) productivity per power; 3) mass per power; 4) power per crushing degree; 5) frequency of jaw oscillations per productivity. Corresponding histograms were constructed for each criterion, Fig. 4.

Analyzing the impact criteria, the following conclusions were formed: 1) the best results in most parameters are achieved by jaw crushers manufactured by Sandvik, Metso, Lipmann; 2) the best results in terms of the impact of power on the degree of crushing are achieved by a vibrating jaw crusher; 3) medium-crushing jaw crushers completely dominate the market compared to jaw crushers with simple jaw movement, provided that the inlet size is up to 1200x1500. This is also reflected in the criterion assessment.

Cone crushers. In cone crushers, the material is destroyed under the action of compressive, abrasive and bending loads between the outer and inner cones. Depending on the design of the crushing machine and its purpose, the inner cone can perform the following types of motion: 1) moving along a circular trajectory, while performing translational motion, Fig. 1.7, a (Telsmith type crushers); 2) oscillating relative to a fixed point, which is called the gyration point, Fig. 1.7, b (gyration crushers and Symons type crushers) [16].

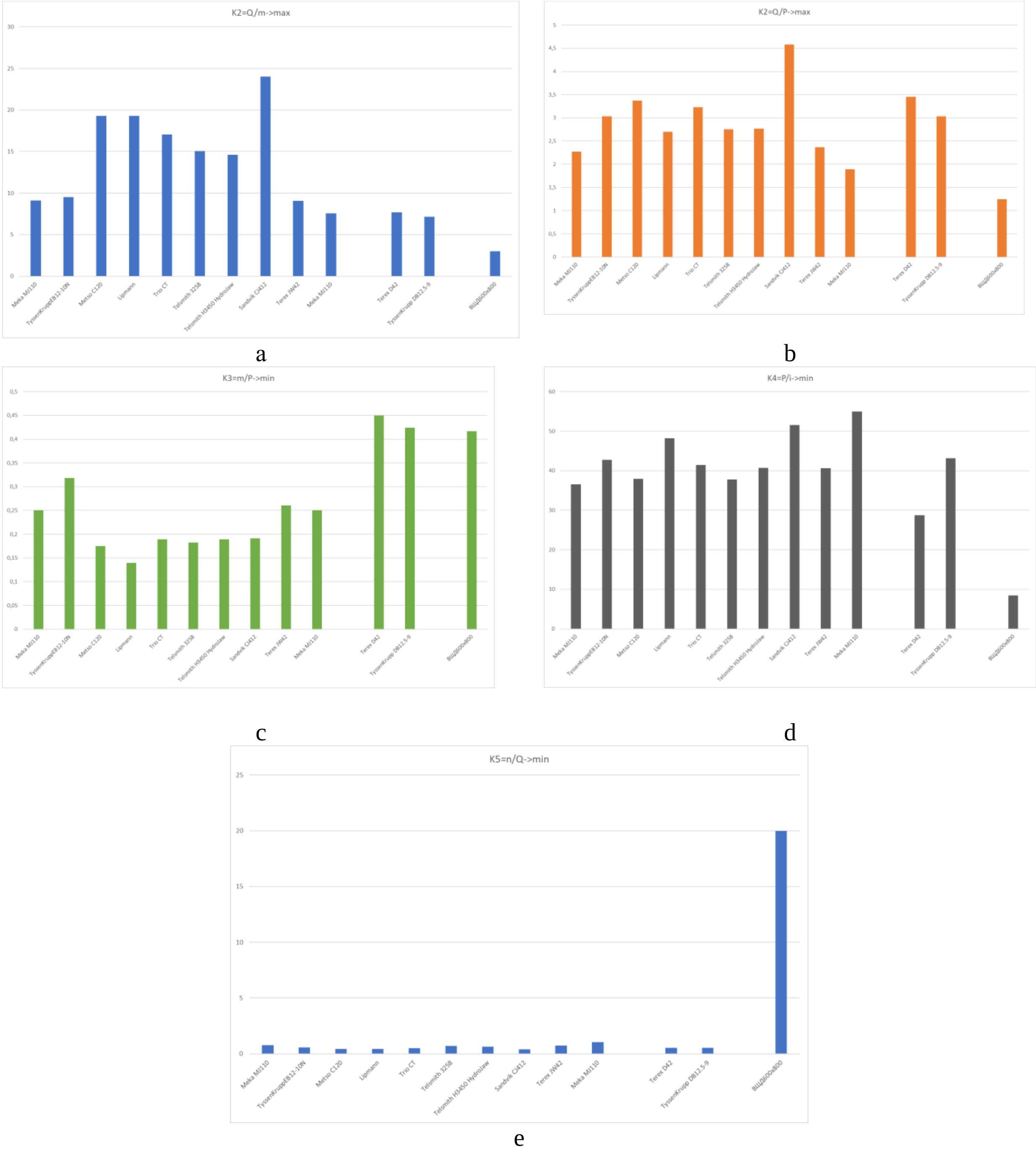


Fig. 4. Histograms of influence coefficients for jaw crushers:
a - productivity per mass; b - productivity per power;
c - mass per power; d - power per crushing degree; e - jaw oscillation frequency per productivity

Crushing in a cone crusher occurs continuously with the sequential movement of the crushing zone in a circle. That is, while one side of the moving cone approaches the fixed cone during rotation, the other side moves away from the fixed cone and the material falls through the annular gap under the action of its own weight.

By design, cones of cone crushers can be steep cones, which are used for crushing large materials, and flat cones, which are used for crushing medium and fine materials. By technological purpose, cone crushers can be classified into:

- cone crushers for coarse crushing (Gyratory Cone Crusher), in which the maximum size of the feed material varies within 400 - 1260 mm, the width of the outlet (Closed Side Setting) is within 75 -343 mm;

- cone crushers for medium and fine crushing (KSD). The size of the input material varies from 40 mm to 414 mm. The width of the outlet varies within 6 mm -50 mm.

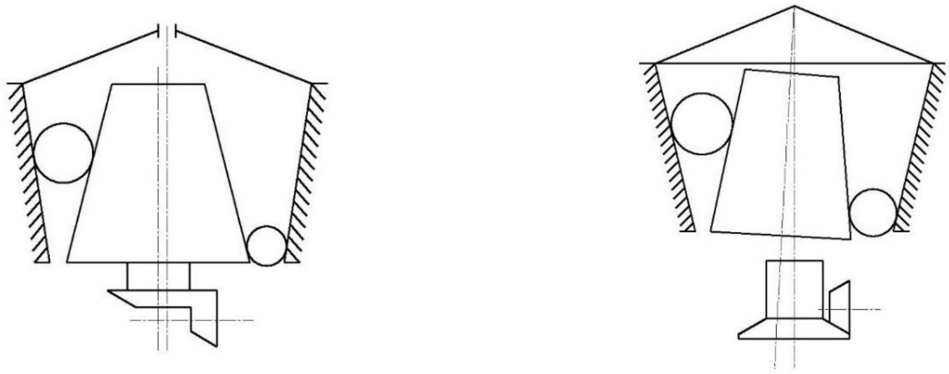


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Fig. 1.7. Schemes of cone crushers:
a – movement of a moving cone along a circular trajectory; b – oscillation of a moving cone relative to a fixed point.

A separate category should be allocated to vibrating cone crushers. In general, vibrating cone crushers can be divided into the following types: 1) with a vibrator on the cone; 2) with a vibrator on the housing; 3) with a vibrator on the housing and cone. It should be noted here that a cone crusher with a vibrator on the cone has practical application [17], [18].

The main types of medium and fine cone crushers are Symons and Telsmith crushers.

The structure of the cone crusher for coarse crushing (gyration) is shown in Fig. 5. The crusher consists of the lower 2, middle 4 and upper 6 parts of the frame. The upper part of the frame is simultaneously a traverse in which the shaft suspension unit 7 is located. The inner surface of the fixed cone 12 and the inner surface of the traverse are lined with replaceable plates 13 and 10. In addition, lined plates 11 and 14 are installed on the outer surface of the traverse and in the lower part of the frame. A movable cone 3 is rigidly fixed on the conical shaft 7, also lined with replaceable plates 5. The eccentric sleeve 1 is installed in a hollow eccentric shaft 20, which is driven by the belt pulley 15, through the drive shaft 16 and the bevel gear 17.

The eccentric hollow shaft 20 itself is installed in the cylindrical cup of the frame 19. The eccentric hollow shaft 20 has an eccentric bore, due to which the lower end of the shaft, when rotating, outlines a conical surface with the apex at the suspension point. A bushing 18 is installed between the cylindrical cup 19 and the eccentric hollow shaft 20. The cone suspension assembly consists of a protective bushing of the main shaft 8 and a bearing 9. When the crusher is operating, the suspension parts and friction pairs withstand high loads. These loads can be reduced by using hydraulic thrust bearings, which in turn are also used to automatically adjust the outlet gap. When starting such crushers in the “under the blockage” mode, an additional engine or a hydraulic unloading system of the crushing chamber can be used. In general, the design of a large-sized cone crusher has remained almost unchanged for more than half a century.

A feature of cone crushers for coarse crushing is that rocks in the crushing chamber are subjected to a complex load from compression and bending. The resistance of rocks to bending is less than the resistance to compression, which gives cone crushers an advantage over jaw crushers in terms of energy consumption for the crushing process. The finished product itself after passing through the crushing chamber of the cone crusher has a more rounded shape, i.e. the percentage of flaky grains is small. The disadvantage is that due to the peculiarities of the cone crusher, namely the rolling of the inner cone over the outer one, these crushers do not work well with viscous material, which can lead to clogging of the crushing chamber. In addition, when crushing viscous materials, energy consumption increases significantly.

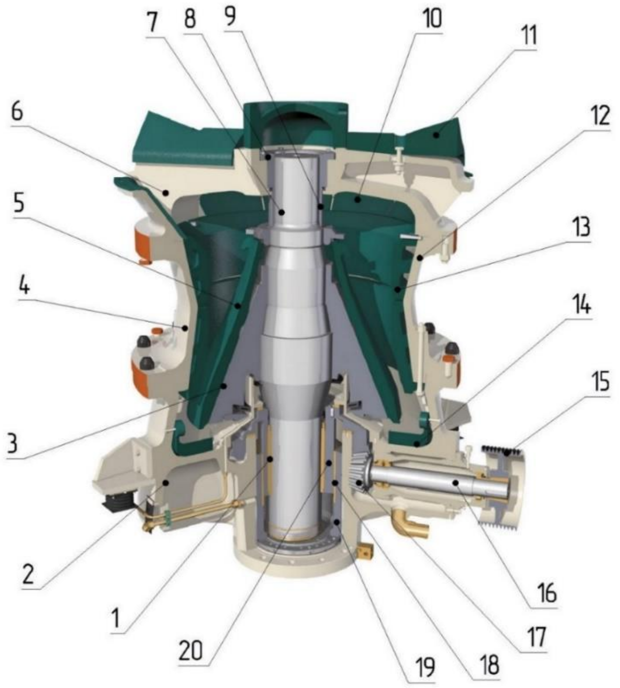


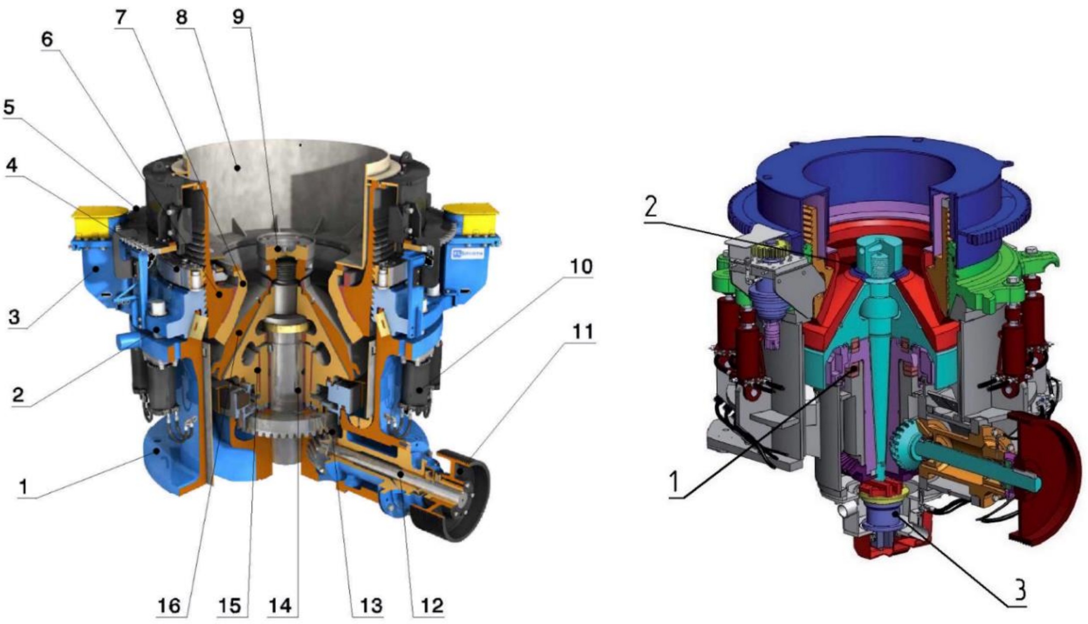
Fig. 5. Structure of a cone crusher for coarse crushing:
1 – eccentric bushing; 2 – lower part of the frame; 3 – movable cone; 4 – middle part of the frame; 5 – lined plate of the movable cone; 6 – upper part of the frame; 7 – shaft; 8 – bushing of the cone shaft suspension unit; 9 – bearing; 10 – inner lining of the traverse; 11 – outer lining of the traverse; 12 – fixed cone; 13 – lining of the fixed cone; 14 – inner lining of the lower part of the frame; 15 – pulley; 16 – drive shaft; 17 – bevel gear; 18 – bushing of the supporting unit of the movable cone; 19 – cylindrical cup; 20 – eccentric hollow shaft

Medium and fine cone crushers have a different structure compared to the coarse cone crusher. The main significant differences are the profile of the crushing chamber, the cantilever shaft, the hydraulic unloading scheme and the support of the moving cone. In medium and fine cone crushers, the moving cone is more widened at the base (the angle at the base varies within 40-42 degrees, while in coarse crushers the angle at the base is 70-80 degrees), this contributes to obtaining a more uniform size of the crushed product. Such crushers are used in the second and subsequent stages of crushing.

The structure of a medium crushing cone crusher is shown in Fig. 6, a.

The crusher consists of a frame 1, a hydraulic system 2, which is designed for quick unloading of the crushing chamber when the crusher is operating “under a blockage” or when an uncrushed object hits it. The principle of operation of the system is to move the rods of the hydraulic cylinders 10, which leads to an increase in the distance between the movable and fixed cones. The hydraulic cylinders 10 themselves are also designed to damp vibrations of the fixed cone of the crusher assembly. The hydraulic drive 3 is designed to change the outlet opening of the crusher (CSS) by rotating the drive flange 5, which is rigidly fixed to the fixed cone, the threaded ring 4 performs the function of locking the threaded ring 2 and the fixed cone 6. Accordingly, the fixed 6 and the movable cones 15 have replaceable lined plates 7 and 16. The loading funnel 8 allows you to maintain a constant loading mode with material. The flange 9 performs the function of locking the movable cone 15 on the shaft 14 from moving the cone along the axis, and also evenly distributes the material along the annular loading hole. The crusher is driven by an electric motor through the pulley 11 of the belt transmission, then through the drive shaft 12 and the bevel gear 13 [19].

In early versions of medium-sized cone crushers, the outlet was adjusted by a hydraulically driven ratchet mechanism. Spring blocks were used to dampen vibrations of the stationary cone. Today, such crushers are also widely used.



a b

Fig. 6. Structure of a cone crusher:
a - medium crushing type Symons (1 - frame; 2 - hydraulic unloading system; 3 - hydraulic drive for changing the size of the outlet opening (CSS); 4 - locking threaded ring; 5 - drive flange; 6 - external fixed cone; 7 - lining of the fixed cone; 8 - loading chute; 9 - locking flange; 10 - hydraulic cylinder; 11 - pulley; 12 - drive shaft; 13 - bevel gear; 14 - conical shaft; 15 - movable cone; 16 - lining of the movable cone)
b - shallow crushing type Telsmith (1 - gyration rolling disc; 2 - wear-resistant cap; 3 - locking tooth)

In terms of structure, fine cone crushers are similar to medium cone crushers, Fig. 6, b. In foreign literature, one can find a classification of medium and fine cone crushers according to the Symons and Telsmith types. These two types include large sizes, which can be attributed to medium crushers by the size of the crushing chamber and CSS, and also include smaller sizes, which can be attributed to fine crushers. The main difference between these two types of crushers is the shape of the crushing chamber and the method of supporting the moving cone.

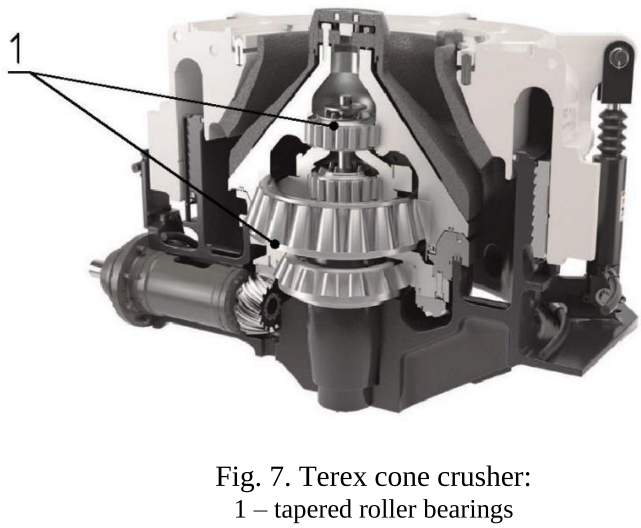


Fig. 7. Terex cone crusher:
1 – tapered roller bearings

Classically, Symons type cone crushers use a spherical sliding support of the inner (moving) cone, Fig. 6, a. At the same time, in Telsmith type cone crushers, the support of the inner cone is a gyration rolling disc 1, Fig. 6, b, which is rigidly connected to the drive eccentric bushing. In addition, the shaft of the moving cone is equipped with a tooth located on its shank. The tooth engages with the corresponding tooth on the bottom of the crusher housing 3, as a result of which the rotation of the cone around its axis is made impossible due to the clamping of the shaft by the drive eccentric, and the displacement of the moving cone on the sliding support bearings at high speeds is neutralized. These design solutions allow to increase the number of circular oscillations of the cone and the degree of crushing [5]. The degree of crushing in the crushers shown in Fig. 6, b can reach 6. In the crusher shown in Fig. 6 instead of a flange with a disk, the movable cone is clamped from axial movement by a special wear-resistant cap 2.

The criteria evaluation of modern models of cone crushers is carried out according to the same parameters as for the jaw crusher. The corresponding histograms are presented in Fig. 8.

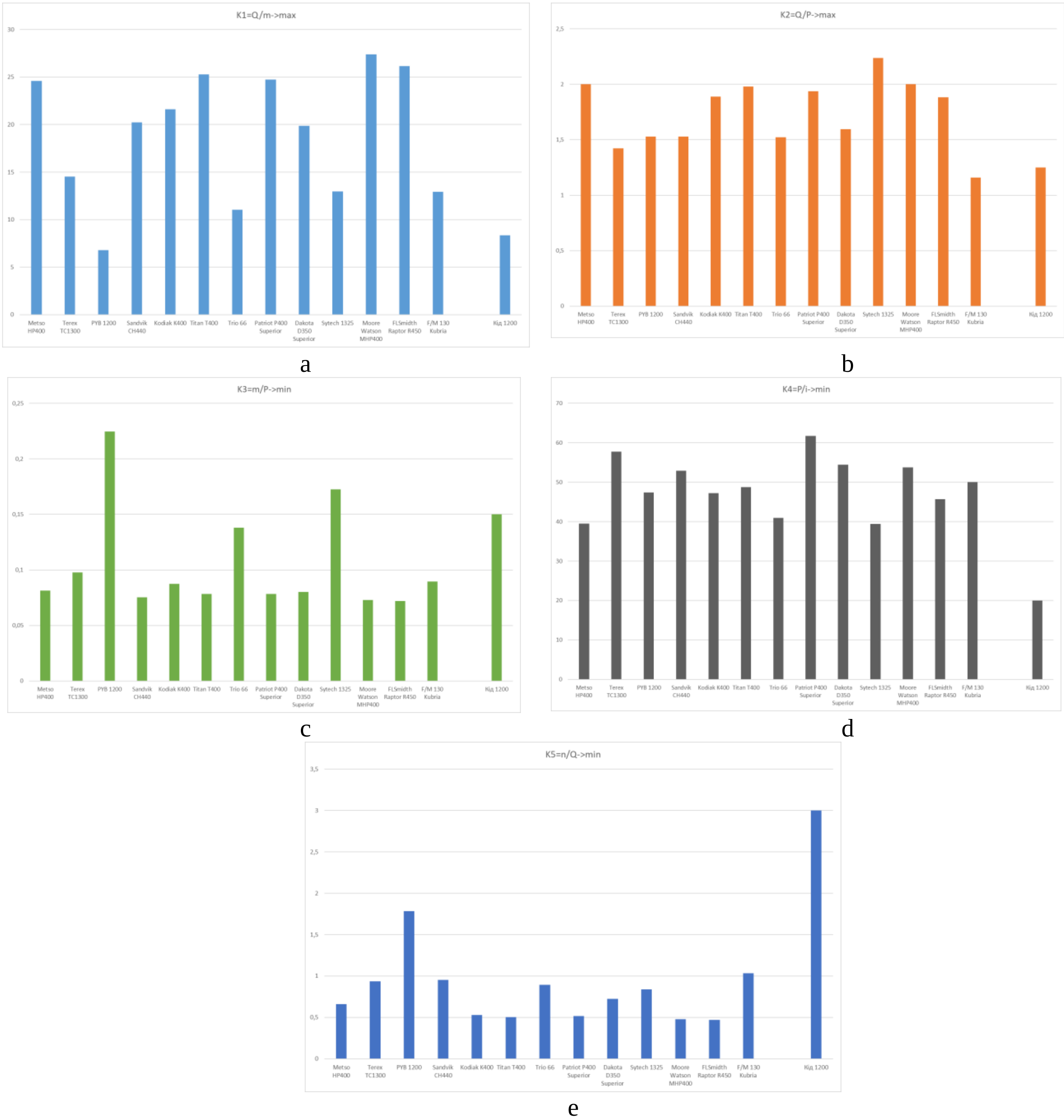


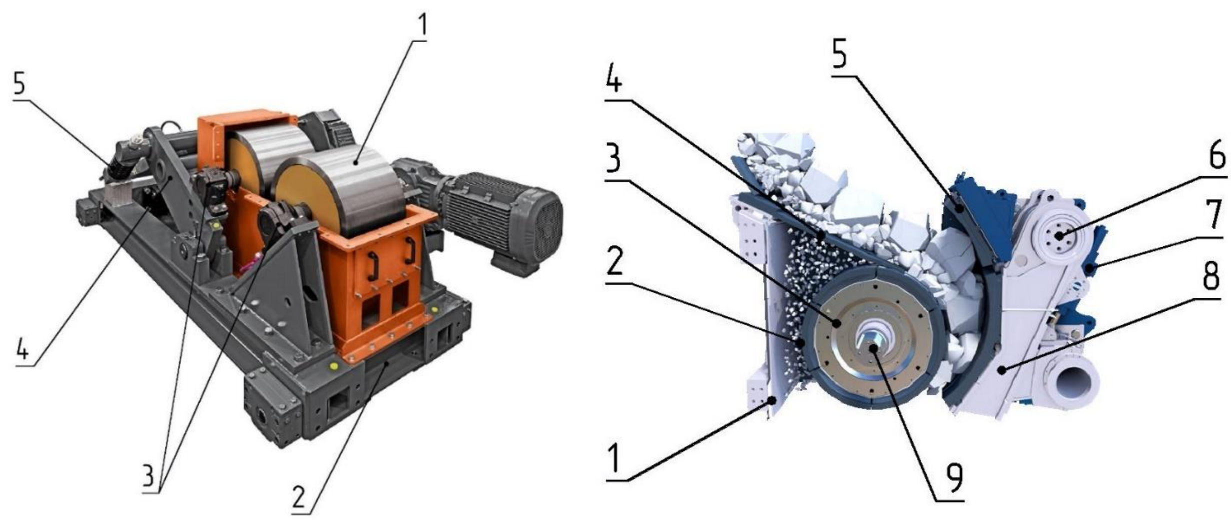
Fig. 8. Histograms of influence coefficients for cone crushers:
a - productivity per mass; b - productivity per power; c - mass per power; d - power per crushing degree; e - cone oscillation frequency per productivity

The main disadvantages of cone crushers are: 1) ellipticity and non-concentricity of the crushing plates of the cones; 2) increased radial clearances in the eccentric drive mechanism; 3) sensitivity to uneven loading; 4) limited frequency of oscillations of the moving cone; 5) lack of means of quantitative optimization of the feed.

The most efficient crushers in terms of coefficients K1-K3 are cone crushers from Metso, Moore Watson and FLSmidth. The best results are obtained in the cone inertial crusher for parameter K4. According to coefficient K5, the difference between the inertial and eccentric models of crushers is smaller compared to jaw crushers.

Roll crushers. Roll crushers are designed for medium and fine crushing of materials of different strengths. The working element of the roll crusher is a roller. Roll crushers with one and two rollers are common.

On Fig. 9, a shows the structure of two roller crushers. The crusher consists of two parallel cylindrical rollers 1, rotating towards each other. A piece of material entering the crushing space between the rollers is captured by friction against the surface of the rollers and is then crushed. The surface of the rollers can be smooth, grooved or toothed. The rollers are mounted on a frame 2 in bearings 3. The bearings of one roller have springs 5, which are compressed when an uncrushed object enters the working space. As a result, the moving roller moves away from the stationary one and the object passes between them through an enlarged gap. To adjust the outlet in the crusher, a mechanism 5 is used, which has a hydraulic drive and moves one roller in the horizontal direction [20].



a б

Fig. 9. Structure of a roller crusher:
a - Siebtechnik Tema; b - FLSmidth

The frequency of rotation of the rolls is usually the same, but there are crushers with different frequencies of rotation of the rolls. They are used for crushing relatively soft material [17].

The degree of crushing of medium and high-strength rocks in two-roll crushers is 3...4, and soft rocks - up to 10. The strength of rocks crushed in roll crushers does not exceed 70 MPa with corrugated rolls and 130 MPa with smooth rolls.

The advantages of roll crushers are simplicity of construction and reliability in operation. The disadvantages of roll crushers include low productivity, while the strength of the crushed material is limited. Therefore, roll crushers require continuous and uniform feeding along the entire length of the roll.

On Fig. 10, b shows an eccentric roller crusher. The crusher consists of a frame 1 to which a grate screen 2 is hingedly fixed at one end. The grate screen is freely placed in the grooves of the lined segment plates 3 of the roller 4 with the other side. The roller 4 is mounted on an eccentric shaft 5, which is driven by an electric motor through a belt drive. Due to the circular oscillations of the roller 3, the material that falls on the grate screen is sieved and the fine fraction smaller in size than the size of the holes between the grates falls down under its own weight without passing through the crushing chamber. At the same time, when the grate screen 2, which has a certain angle of inclination, vibrates, the material enters the crushing chamber of the eccentric roller crusher. When the roll 3 moves in the direction of the fixed cheek 5, which is lined with plates 6 and fixed on the axis, the material is crushed. The outlet opening is adjusted, as well as the passage of uncrushed material is carried out by the hydraulic drive 7 of the fixed cheek.

A common type of roller crusher is the high-pressure grinding roll (HPGR). This type of roller crusher was developed by Schonert [21]. This type of crusher has high compressive forces. Today, there is a tendency to replace medium and fine cone crushers with HPGR roller crushers. HPGR crushers are widely used in the field of enrichment.

In high-pressure crushers, the material to be crushed is crushed due to compression that exceeds the compressive strength of the material, as well as due to interparticle fracture. That is, when a large amount of material is held between the rolls and subjected to high pressure, that is, grinding can occur due to compression forces and due to interparticle fracture. To ensure interparticle fracture of the material, the condition of exceeding the pressure of the rolls above the compressive strength of the material must be clearly met. In studies [22,23] it was found that in the process of crushing the material by applying large compressive forces to the material, the total energy spent on the destruction process will be less than in crushing machines where impact loads prevail.

The working principle of the high-pressure roller crusher is as follows. At the initial stage, when the material is fed to the working space between the rolls (the size of the material is larger than the gap between the rolls), it undergoes ordinary destruction due to compression and friction forces. Then, due to gravity and friction forces, the material falls directly into the gap between the rolls, where it undergoes significant compression, as a result of which many particles are destroyed and compacted, which leads to the transfer of a larger number of interparticle compression forces, which further destroy the particles. Due to significant compaction at the exit of the crusher, a product is obtained in the form of a continuous ribbon. After that, the continuous product is loaded into the mill for its dispersion.

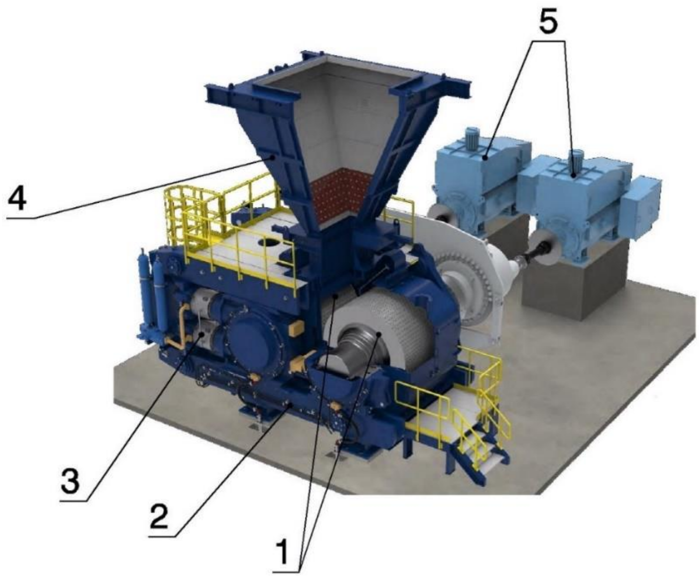
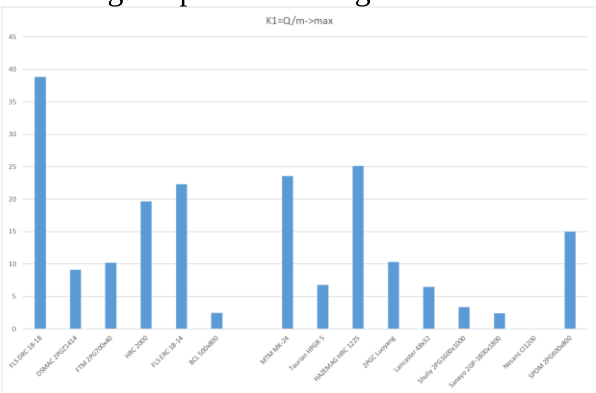


Fig. 10. Structure of the HPGR high-pressure roller crusher:
1 – rollers; 2 – frame; 3 – hydraulic cylinders; 4 – feeder; 5 – drive motors

Significant compression forces in HPGR type roller crushers are created by hydraulic cylinders that press the moving roller against the stationary one and regulate the gap between the rollers. The crushing pressure in such crushers varies from 50 MPa to 250 MPa. The dimensions of the rollers vary within 0.7 - 2.8 m with a length to diameter ratio of 0.2 to 0.6. The speed of the rollers is taken within 85-100 rpm. The productivity of such crushers varies from 20 t/h to 750 t/h. Fig. 10 shows the structure of the HPGR high-pressure roller crusher.

The HPGR crusher consists of a frame 2 in the bearings of which the rollers 1 are installed. One of the rollers is stationary, and the other, on the contrary, can move in the horizontal direction by moving the rods of the hydraulic cylinders 3. Thus, the necessary pressure is created in the working space of the crusher for the destruction of the material. For uniform supply of material to the working space of the rollers, a feeder 4 is mounted on the crusher frame. The crusher is driven by electric motors 5.

Fig. 12 presents histograms of the criteria evaluation of roll crushers.



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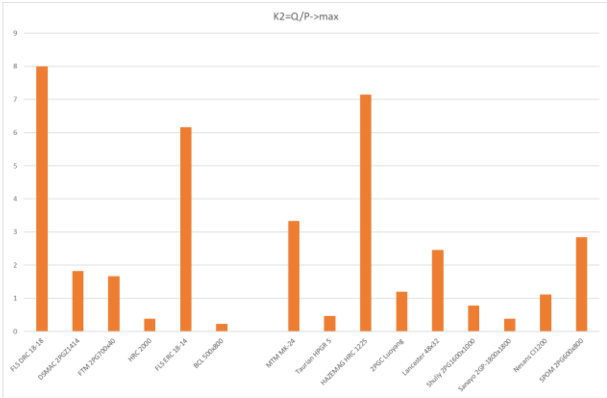

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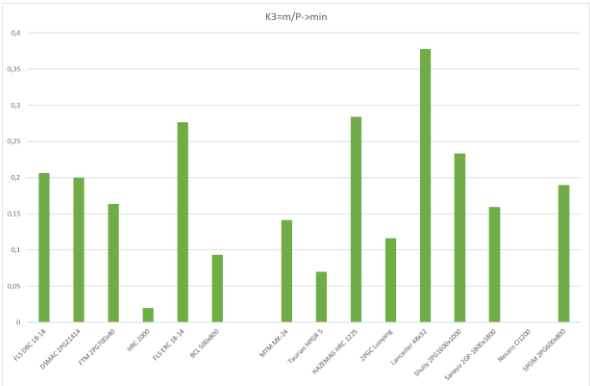

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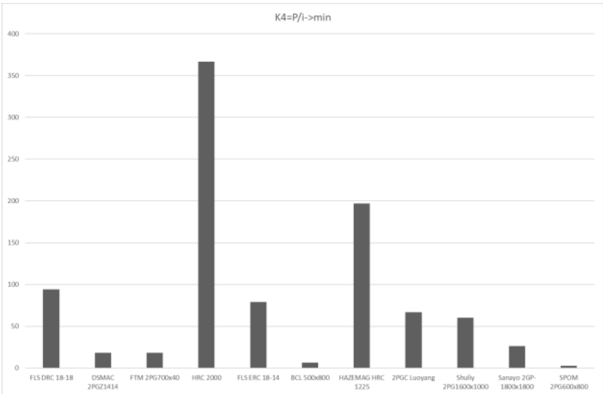

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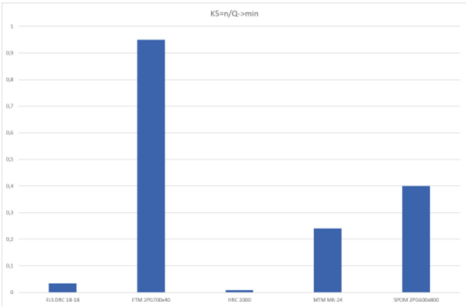


e

Fig. 11. Histograms of influence coefficients for roller crushers:
a - productivity per mass; b - productivity per power; c - mass per power; d - power per crushing degree; e - speed per productivity

Based on the criteria assessment, it can be noted that the best designed crushers are those made by FLSmidth, Hazemag, and Metso. In general, the most popular roll crushers are HPGR high-pressure crushers, which are mainly used in the processing of solid materials, especially in the enrichment sector. However, roll crushers with smooth rolls are still used only for medium and shallow crushing, which is associated with the geometry of the working surfaces. That is, the ratio between the roll diameter and the source material is within 1: (17-20). This indicates that in order to obtain material fractions of 75 mm, a roll crusher of considerable mass is required. Of course, this ratio is smaller when using corrugated roll surfaces and is 1: (2-6). A promising design of a roll crusher today is an eccentric roll crusher, which is manufactured by FLSmidth. By combining the design of the roll and jaw, it was possible to increase the productivity of such a crusher, eliminate dust clogging of the crushing chamber and its overloading, reduce energy consumption, and increase the degree of crushing.

Impact crushers. The principle of operation of impact crushers is based on the destruction of the material entering the crusher by the mechanical impact of the rotating working elements and the crushing of the discarded pieces of material against the impact plates installed in the middle of the crushing chamber.

Impact crushers are designed for coarse, medium and fine crushing of materials with a strength of up to 200 MPa. The main unit of the impact crusher is the rotor, which has a large mass and a rotational speed of up to 80 m/s, which ensures effective crushing of the material.

The advantages of impact crushers are simplicity of design, reliability in operation, low energy consumption, relatively higher product quality, the degree of crushing can reach 40. The disadvantages include the high intensity of operation of the working elements.

Impact crushers can be classified into two groups: 1) rotary crushers; 2) hammer crushers [24].

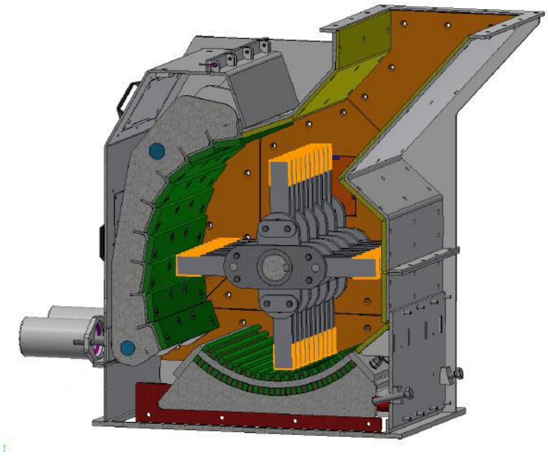
Hammer crushers come with one or two rotors, reversible and non-reversible, with or without a grate. In hammer crushers, the working elements are hammers, which are hingedly mounted on a disk-rotor rotating at high speed.

Rotary crushers can be classified into two groups: 1) horizontal shaft rotary crushers (HSI); 2) vertical shaft rotary crushers (VSI or centrifugal impact crushers).

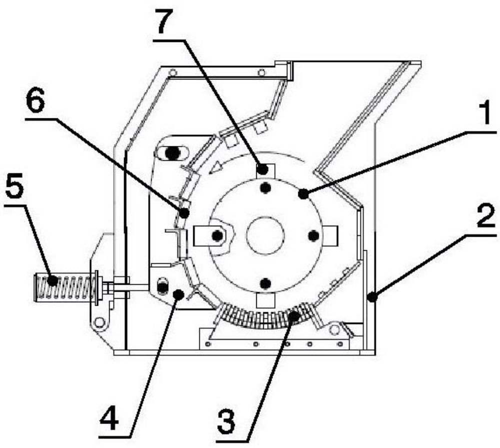
In horizontal shaft rotary crushers, the working elements are hammers, which are rigidly mounted on a rotating rotor; in this case, the impact force on the material is determined by the total mass of the rotor and hammers.

Let us consider the structure of the hammer crusher, which is presented in Fig. 12. A single-rotor hammer crusher consists of a rotor 1, a housing 2, a baffle plate 4, a grate 3. The rotor is driven by an electric motor through an elastic coupling. The inner walls of the housing are lined with replaceable plates 6. A spring mechanism 5 is provided to protect the crusher from clogging. Hammers 7 are hingedly mounted on the rotor shaft.

The main parameters of the hammer crusher are: 1) rotor diameter; 2) rotor length; 3) hammer length; 4) productivity; 5) power.



a

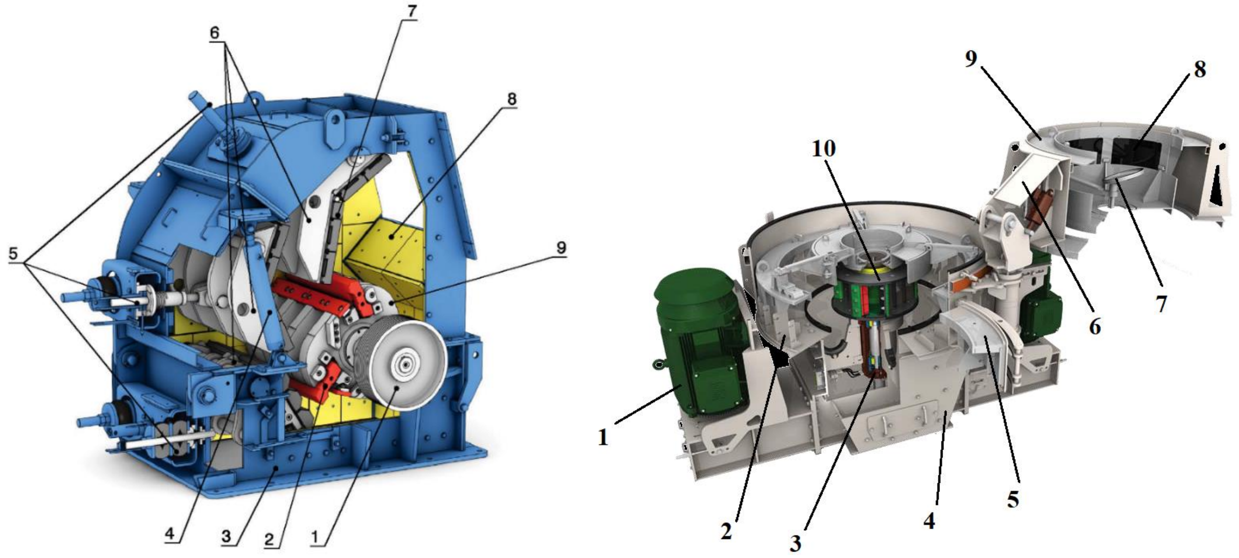


b

Fig. 12. Single-rotor hammer crusher:
a – section; b – diagram

The structure of a horizontal shaft rotary crusher (HSI) is shown in Fig. 13, a. The principle of operation of a horizontal shaft rotary crusher (HSI) is as follows. The output material enters the rotor 9 rotation zone via a tray 8, where it is subjected to impact loads from the rotor 9 blades 2. The crusher crushing chamber is formed by the rotor 9 and the impact plates 6. The impact plates have linings 7. To adjust the degree of crushing, the distance between the lower edges of the impact plates and the rotor blades is changed using spring-loaded rods 5, which simultaneously play the role of a protective mechanism for the machine against damage when the crushing chamber is clogged with either oversized material or non-crushed material. For ease of maintenance, the upper part of the crusher housing is detachable. In this regard, the crusher is provided with a jack mechanism 4 for moving the upper part of the housing. A pulley 1 is installed on the cantilever part of the rotor 9 of the crusher, from which the crusher is driven by a belt drive and an electric motor.

The main design parameters of the HSI rotary crusher are: 1) rotor diameter; 2) rotor length; 3) energy consumed for material destruction; 4) power; 5) productivity [25].



a b

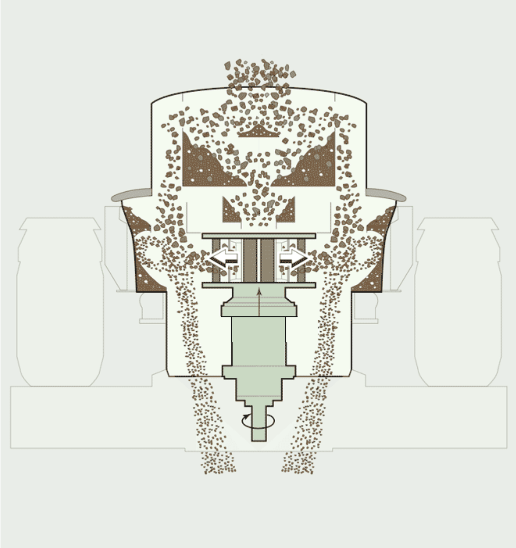
Fig. 13. Structure of a rotary crusher:
a – with a horizontal shaft HSI (1 – pulley; 2 – hammer; 3 – frame; 4 – jack mechanism; 5 – rods; 6 – impact plate; 7 – lining; 8 - tray; 9 – rotor); b – with a vertical shaft VSI or centrifugal impact (1 – engine; 2 – impact frame; 3 – shaft; 4 – frame; 5 – inspection hatch; 6 – cover lifter; 7 – device for adjusting the angle and height of the distributor plate to adjust the power supply; 8 – windows that are adjustable for the passage of material; 9 – cover; 10 – rotor)

Rotary crushers with a vertical shaft VSI have a significant difference from rotary crushers with a horizontal shaft HSI. In foreign classification, rotary crushers are classified according to the action of the working body on the material and the destruction process itself. Therefore, such crushers have a common name - impact crushers with either a horizontal shaft (HSI) or a vertical shaft VSI. If we consider hammer crushers, then according to the existing design they also come with a horizontal shaft and a vertical shaft. However, due to the absence of significant differences in the designs of hammer crushers, the emphasis on classification by shaft location is not made.

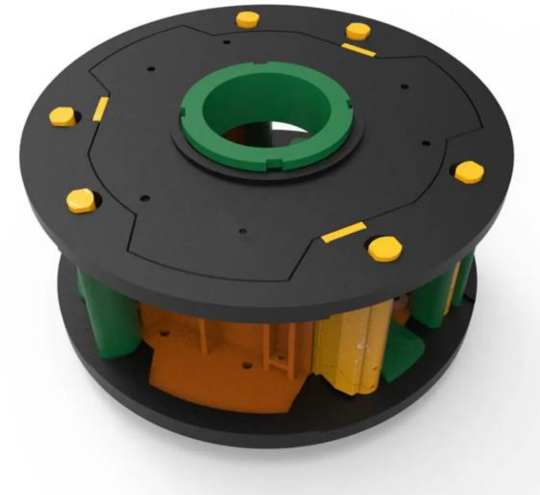
Within Ukraine, VSI vertical shaft rotary crushers are better known as centrifugal impact crushers. A vertical shaft rotary crusher implements the principle of material destruction by free impact in a field of centrifugal forces. The main element of centrifugal impact crushers is the rotor, which is located on a vertical shaft [26]. The rotor is equipped with accelerating elements in the form of internal channels of complex shape. The material to be crushed is fed into the central part of the rotor, accelerated by the accelerating elements and thrown at high speed onto the reflecting surfaces located on the periphery of the crushing chamber, where it is destroyed upon impact.

In a crusher of this type, material crushing is implemented according to 3 different schemes: impact with an obstacle, impact of pieces with each other, and impact with moving structural elements.

The main difference between centrifugal impact crushers and other impact devices is that the crushing action is almost completely shifted from the rotating working body to the peripheral reflecting surface. The rotor performs only the dispersing function. Fig. 14, a shows the principle of operation of the centrifugal impact crusher, and Fig. 14, b shows the rotor design.



a



b

Fig. 14. VSI centrifugal impact crusher:
a – working diagram; b – rotor

In centrifugal impact crushers of the VSI type, two material destruction schemes can be used. The first scheme is the classic one, in which the material accelerated by the rotor hits the inner wall of the crusher housing at high speed, as a result of which it undergoes destruction. This scheme is called “stone on metal”. The inner wall of the crusher housing is lined. The second scheme is called “stone on stone”. In this scheme, part of the material that is fed into the crusher feeder through special windows is directed into the space between the rotor and the inner housing of the crusher. This process of feeding the crusher is called cascade feeding. That part of the material that enters the rotor is accelerated in the rotor and, flying out of the rotor at high speed, meets the material that was directed outside the rotor. As a result of the impact of one particle of material on another freely falling particle of material, their mutual destruction occurs.

It should also be noted that the inner lined wall of the crusher, which is located parallel to the rotor outlet holes, has recesses in the form of pockets. These recesses are made to create a self-lining layer. Such a layer is formed by clogging the pocket with material that flies out of the rotor at the initial stage of the crusher's operation. This leads to an increase in the service life of the lining plates of the inner walls of the crusher.

Today, the company produces a wide range of centrifugal impact crushers. The power of such crushers ranges from 37 kW to 600 kW, and the productivity from 40 tons/h to 775 tons/h. The size of the feed product ranges from 30-64 mm. The basic design of the Barmac VSI series centrifugal impact crusher is shown in Fig. 13, b.

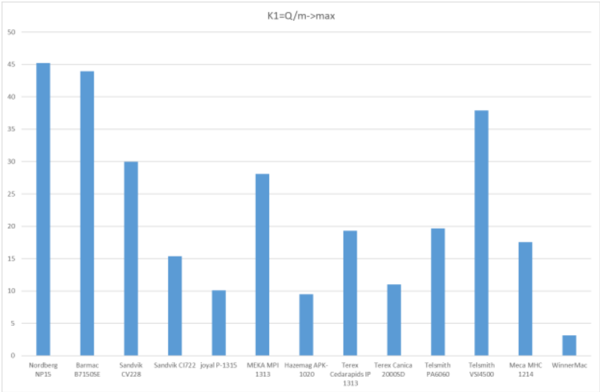
In the Barmac VSI series crusher, it is possible to vary the following parameters: 1) change the rotor rotation speed; 2) select the type of crushing chamber profile; 3) adjust the ratio of material flows in the cascade feed system; 4) select the rotor diameter.

Figure 15 shows the criteria for evaluating impact crushers. HSI, VSI, and hammer crushers were included in the analysis.

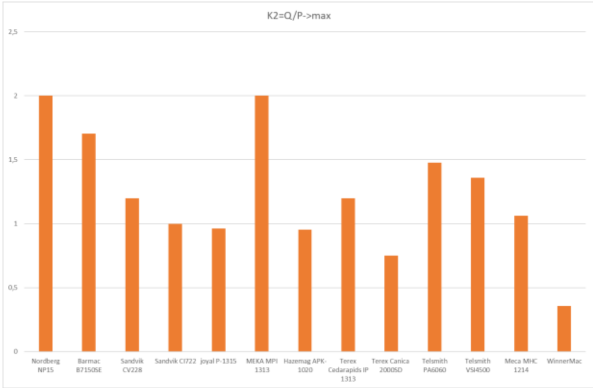
The best designs based on the criteria analysis in Fig. 15 are possessed by rotary crushers from Metso, Telsmith and Sandvik.

The difference between horizontal shaft rotary crushers and hammer crushers, in addition to the design features of the rotor, is as follows: 1) rotary crushers are designed for crushing hard and wet materials, while hammer crushers are used for large-scale and high-performance production lines that process medium-hard materials with a moisture content of no more than 10%; 2) a rotary crusher is usually used for secondary crushing and requires additional equipment for the first crushing stage (jaw crusher), a hammer crusher can be used for single-stage crushing; 3) a hammer crusher is prone to clogging of the crushing space due to being equipped with a lower sieve plate;

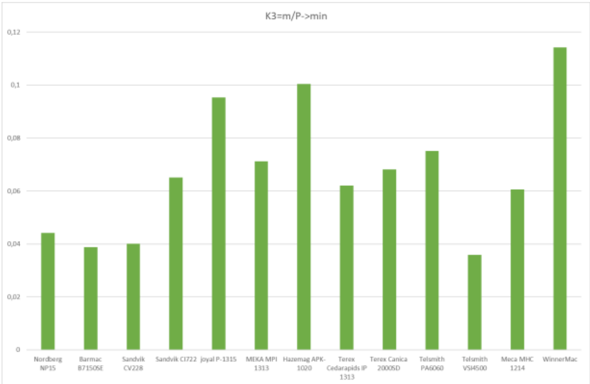
4) a hammer crusher has higher productivity; 5) the degree of crushing is higher in a rotary crusher (can exceed 50, this applies to crushers with a vertical shaft); 6) in hammer crushers, the wear of the hammers is more significant than that of the working elements of the rotor in a rotary crusher.



a



b



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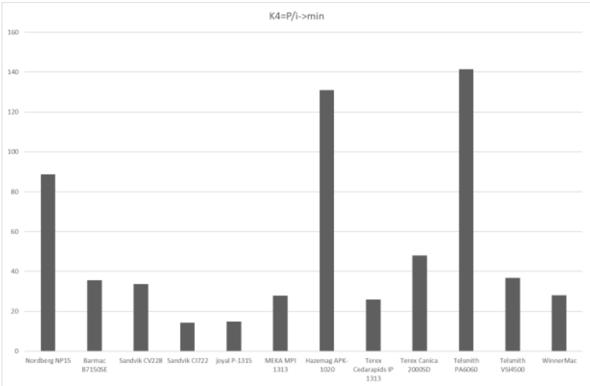

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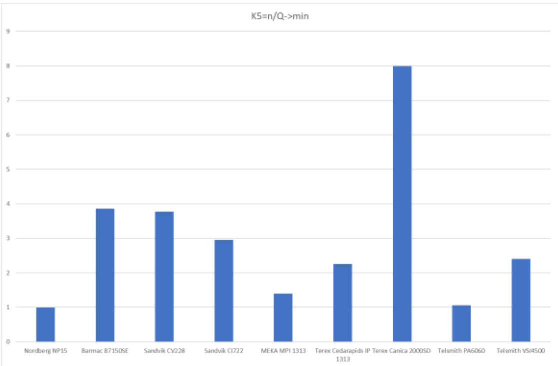

e

Fig. 15. Histograms of impact coefficients for impact crushers:
a - productivity per mass; b - productivity per power; c - mass per power; d - power per degree of crushing; e - speed per productivity

Separately, among the features of horizontal shaft rotary crushers, one can highlight the possibility of selective crushing. That is, the finer material is screened out through the grates and does not enter the crushing chamber, which leads to a uniform output of the product with the same strength, reduced energy consumption and no clogging of the crushing chamber. The advantages of vertical shaft rotary crushers are increased productivity with a relatively small weight of the structure, a high degree of crushing and an increased service life due to the formation of a lining layer of crushing material during the operation of the machine.

Among the promising designs of hammer crushers is a crusher with a hinged vertical rotor [4]. The productivity of such crushers can reach 100 t/h and process materials of medium strength. The advantages of such a crusher include the possibility of cascade feeding, flexible control of the degree of crushing, control of crushing energy, ease of replacement of working elements. On the other hand, this design of the crusher is still at the stage of experimental research and has not been launched into series. Another promising design of the hammer crusher is the DIM-800k. This crusher uses an active method of impact crushing. The design of the crusher includes 3 rotors - one guide and two deflectors. The material entering the crushing chamber is accelerated by the guide rotor, after which it is thrown onto the deflector rotors. The maximum degree of crushing can reach 200. The maximum productivity is 120 t/h.

6. Conclusions. The types of crushing machines that have the most advanced design were identified. The design features of crushers, the advantages and disadvantages of individual types of crushing machines, and the directions of their development were considered.

For jaw crushers, the main areas of development are: 1) optimization of the crusher design; 2) improvement of the surface geometry of the crushing plates; 3) development and creation of modular crushing units based on the jaw crusher, which include the jaw crusher (mobile crushing and crushing-sorting complexes, crushing buckets, etc.); 4) change of the crusher kinematics in order to create a vibration or impact effect on the material; 5) development and improvement of hydraulic systems for adjusting the parameters of the mechanical mode.

In cone crushers, the main directions are: 1) development and improvement of hydraulic systems for regulating the parameters of the mechanical mode; 2) development and improvement of the design and support of the moving cone; 3) creation of inertial and vibration cone crushers; 4) improvement of the geometry of the crusher's working elements.

Directions for the development of roller crushers: 1) creation of high-pressure rollers with a massive frame for large production volumes; 2) development and improvement of a synergistic design that combines an eccentric cheek and roller; 3) improvement of the geometry of the crusher's working elements.

Among impact crushers, horizontal and vertical shaft rotary crushers (HIS, VSI) have become widespread, and work is underway to create and improve the designs of vertical shaft hammer crushers and those with an active impact crushing method. The following are promising areas of development: 1) optimization of the crusher design; 2) improvement of the kinematic characteristics of the rotor; 3) improvement of the geometry of the rotor's working elements (hammers, billets).

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