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TECHNIQUE FOR CALCULATION OF PARAMETERS OF THE WAVE PROFILED ROLL CRUSHER FOR OBTAINING THE CUBIC SHAPED PRODUCTS

[1]Tytov O.O., [2]Babii K.V., [2]Sukhariev V.V.

[1]Dnipro University of Technology, [2]Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine

Abstract. The purpose of this work is to develop a technique for calculating the crusher with wave profiled rolls based on analytical and experimental data on hard rocks processing in crushers of this type. Information on the expediency of using cubic-shaped products as fillers for concrete is given. Attention is focused on the advantages of this approach. The main types of equipment capable of producing the stone products with minimum content of lamellar pieces are analyzed. The choice of crushers with wave profile of rolls for processing of narrow-sized crushed stone fractions as combination of high efficiency with acceptable wear of working surfaces and low dynamics of working modes is justified. The algorithm of calculating the crusher parameters is given based on theoretical conclusions and experimental data on the fine crushing of hard rocks from open pits of Ukraine on the real sample of crusher with wave profiled rolls. Granulometric characteristics of narrow-sized fractions, based on the results of material screening using slits with round and slot openings, the yield of lamellar pieces in the feed material, the coefficient of material friction on the roll working surface, the circumferential speed of roll ledges are taken as initial data. Such parameters of the crusher, as the size of the gap between ledges of the opposite rolls, the nominal diameter of the rolls, the pitch of the roll ledges in the axial direction, the radii of rounding of the ledges and the hollows file of the roll profile, the angle of sharpening of the rolls, the angle of inclination of the taper sections, the height of the profile, the length of the roll working part, the rotational speed of the rolls, the theoretical output of the crusher are determined on the basis of the authors' previous studies. Also, the model example of calculation of crusher parameters for processing of granite fraction of size less than 70 and more than 40mm, having 30% yield of lamellar pieces, is given.

The following conclusions were made. Firstly, the technique for calculating the parameters of crusher with wave profiled rolls for processing the narrow-sized crushed stone fractions in order to reduce the content of lamellar pieces makes it possible to determine the expediency of complete or partial shape improvement of the pieces of narrow-sized crushed stone fractions. Secondly, it sets the main characteristics of the crusher working member and its drive. Thirdly, it is recommended for calculating the parameters of operational part of the crushers with wave profiled rolls, designed to improve the shape of pieces of narrow-sized fractions of construction crushed stone from hard rocks, which are used as filler in responsible concrete and asphalt-concrete products.

Keywords: roll crusher, wave profile, calculation technique, lamellar piece, narrow-sized fraction, slot sieve.

1. Introduction

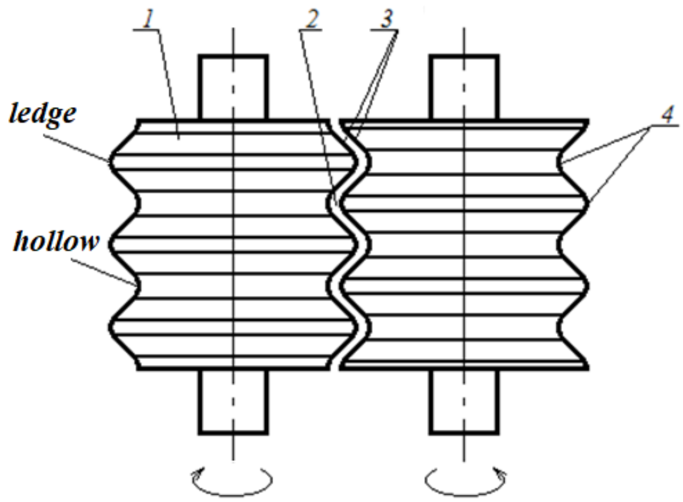
Roll crushers are widespread equipment in the industry for rocks crushing. Toothed, ribbed and smooth rolls are used, the latter at the stage of fine crushing [1]. This stage is considered to be the most responsible in terms of the product quality control, because these products are directed either to the further milling process or to the final consumer.

Fine crushing products are used during production of construction materials, including as fillers for concrete. It is recommended to use only crushing products having rounded or cubical shape of pieces, in the case of production of particularly critical structures operating under conditions of high dynamic loads. This allows to save binders, to ensure more dense laying of carcass particles in concrete and asphalt-concrete products made of crushed stone and, in general, to provide higher carrying capacity and consumer properties of these products [2].

The analysis of scientific and technical information made it possible to identify such a fact that most traditional crushers operating at the stage of fine crushing are unable to produce crushed stone with a minimum content of lamellar pieces [3]. This is especially true for the cone crushers, as well as for the jaw crushers and the roll crushers with smooth or ribbed rolls. Individual types of crushers, for example, the hammer ones, are capable of producing cubical products [4], but they are characterized by high wear of working surfaces, the need to balance the rotors after each change of hammers, which is to be carried out quite often while processing of hard materials.

It is also found, that calculation and choice of the parameters of existing equipment is carried out taking into consideration only the size of processed material pieces, disregarding the parameters characterizing the shape of the pieces.

To solve this issue, the Institute of Geotechnical Mechanics has been conducting for several years the research work on the study of roll crushers with the wave profiled rolls [5], Fig. 1. They combine the advantages of traditional crushers, such as the quasi-static loading of material with a low level of dynamics, the sufficient strength and the appropriate wear resistance of working elements, with, at the same time, the efficient reduction of lamellar pieces yield in crushing products [6]. This is achieved due to the selective destruction of the lamellar pieces under bending loads, which occur during the pieces compression between the ledges of opposite rolls being stagger arranged [7].



1 – bandage; 2 – gap; 3 – conical sections; 4 – roundings

Figure 1 – Scheme of the wave profiled rolls

In this regard, the IGTM of the National Academy of Sciences of Ukraine developed a especial technique for calculating the parameters of crusher with wave profiled rolls, in order to obtain narrow fractions of crushed stone with a minimum content of lamellar pieces. It is intended for determining the crusher structural parameters, such as the diameter and the length of rolls, the pitch and the height of ledges on working surfaces of rolls, as well as technological parameters, such as the size of the slot between the ledges of adjacent rolls in radial direction, the expected output of material and the content of lamellar pieces in products, depending not only on the grain size distribution, but also on the shape of feed material pieces.

The technique allows to determine the rational parameters of the roll crusher operational part in order to improve most efficiently the shape of pieces in crushing products.

The technique's area of application is the calculation of parameters of the crushers with wave profiled rolls designed for further improvement of the shape of pieces of narrow-sized fractions of products of hard rocks fine crushing, produced by traditional equipment, with the minimum degree of crushing and the minimum discharge yield.

The purpose of this work is to develop a technique for calculation of crusher with wave profiled rolls based on analytical and experimental data on hard rocks crushing in crushers of this type.

The idea of work is to assess the need to improve the shape of pieces of the stone material grain size class based on the initial content of lamellar pieces in a given grain size class.

2. Methods

The method of calculation is based on theoretical conclusions and experimental data on fine crushing of hard rocks from open pits of Ukraine conducted by a real sample of the crusher with wave profiled rolls [8]. It is intended for the case of crushing a narrow-sized material fraction, in which the maximum and minimum sizes of the openings of control round sieves differ by not more than 2 times, in order to improve the shape of the pieces, that is, to reduce the yield of lamellar pieces.

3. Results and discussion

3.1. Algorithm for determination of crusher parameters.

Initial data:

- the maximum size of round sieve opening for narrow-sized fraction of feed material $d_{0,max}$, m;

- the minimum size of round sieve opening for narrow-sized fraction of feed material $d_{0,min}$, м (not less than 0.5 of $d_{0,max}$);

- the yield of lamellar pieces in feed material γ_0;

- the bulk density of feed material ρ_b, kg/m^3;

- the values corresponding to results of the feed fraction screening on *i*-subfraction with the help of slot sieves:

$s_{0,i}$, $s_{0,i+1}$ are the sizes of boundary slot sieves, mm;

α_i is the yield of *i*-subfraction in the feed fraction;

γ_i is the yield of lamellar pieces in *i*-subfraction.

f is the coefficient of the material friction on the roll working surface;

υ is the circumferential speed on the ledges of the rolls, m/s.

It is necessary to determine:

1) the possibility to improve the shape of the feed fraction pieces due to additional processing in a crusher with wave profiled rolls;

2) the yield of the fraction (or its subfraction) to be processed;

3) the rational design and technological parameters of the roll crusher operational

part.

Calculation algorithm.

1. If the yield of lamellar pieces in the fraction is more than 15%, then improving the shape of its pieces to better classes with a lower content of lamellar pieces (due to additional crushing with a small degree of size reduction) is advisable.

2. Only those sub-fractions are the subject to processing, which are not classified according to the form of pieces as "rounded" or "cubical," according to the classification of the standard [9], that is, which have the yield of lamellar pieces more than 15%.

3. Determination of the rational design and technological parameters of the crusher operational part.

The slot size between the roll ledges (Fig. 2):

$$b = k_s s_{0,max}\text{, m,} \tag{1}$$

where $s_{0,max}$ is the maximum size of the boundary slot of the maximum sized subfraction being directed to improve the shape, m; k_s is an empirical coefficient.

The minimum value of the roll nominal diameter (by ledges):

$$D_{1,min} = \frac{s_{0,1} - b\sqrt{1+f^2}}{\sqrt{1+f^2} - 1}\text{, m.} \tag{2}$$

The maximum pitch of the roll ledges in axial direction:

$$l_{max} = k_l d_{0,min}\text{, m,} \tag{3}$$

where k_l is an empirical coefficient.

The minimum pitch value of roll ledges in axial direction is:

$$l_{min} = 2d_{dis}\text{, m,} \tag{4}$$

where d_{dis} is the maximum size of discharge pieces, m.

The maximum radius of the roll profile ledges rounding is:

$$r_{1,max} = 0.1d_{0,min}\text{, m.} \tag{5}$$

The minimum radius of the roll profile ledges rounding according to the wear resistance conditions is equal to:

$$r_{1,min} = 0.001 \text{ m} = 1 \text{ mm}. \quad (6)$$

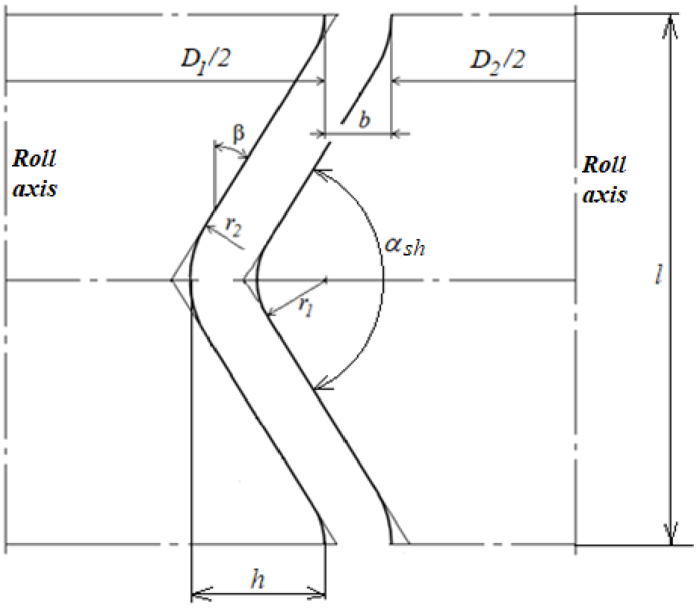


Figure – 2 Design parameters of the wave profile (within single wave)

The radius of roll profile hollow rounding is:

$$r_2 \geq r_1 \text{, m.} \quad (7)$$

The angle of sharpening of rolls ledges for hard rocks is:

$$\alpha_{sh} \geq 90^\circ . \quad (8)$$

The angle of inclination to the symmetry axis of the roll profile taper sections is:

$$\beta = 90^\circ - 0.5\alpha_{sh} . \quad (9)$$

The height of the roll profile (the span between the ledge and the hollow in radial direction) is:

$$h = 0.5l \cdot \tan\beta - (r_1 + r_2)\frac{1 - \cos\beta}{\cos\beta} \text{, m.} \quad (10)$$

The diameter of rolls by the bottom of hollows is:

$$D_2 = D_1 - 2h \text{, m.} \quad (11)$$

The length of the roll working part is:

$$L = 0.7D_1, \text{ m.} \quad (12)$$

The roll speed is:

$$n = \frac{\upsilon}{\pi D_1}, \text{ s}^{-1}. \quad (13)$$

The theoretical volume capacity of crusher is:

$$Q = \mu b L \upsilon, \text{ m}^3/\text{s}, \quad (14)$$

and the recommended fill factor is $\mu = 0.25$.

The theoretical mass capacity of crusher is:

$$Q_M = \rho_b Q, \text{ kg/s.} \quad (15)$$

3.2. Model example.

Let’s consider the following model example.

The granite fraction of size minus 70 plus 40mm, having the yield of lamellar pieces of 30% is used as the product of a fine cone crusher.

The initial data:

$$d_{0,max} = 0.07 \text{ m} = 70 \text{ mm};$$

$$d_{0,min} = 0.04 \text{ m} = 40 \text{ mm};$$

$$\gamma_0 = 0.30;$$

$$\rho_b = 1400 \text{ kg/m}^3;$$

The results of the feed fraction screening on slot sieves with opening size values $s_{0,1}$= 0.028 m = 28 mm and $s_{0,2}$ =0.02 m = 20 mm:

$$+28\text{: } \alpha_1 = 0.52; \ \gamma_1 = 0.11;$$

$$-28+20\text{: } \alpha_2 = 0.30; \ \gamma_2 = 0.40;$$

$$-20\text{: } \alpha_3 = 0.18; \ \gamma_3 = 0.67;$$

$$f = 0.3;$$

$$\upsilon = 4.5 \text{ m/s.}$$

Calculation procedure.

1. The yield of lamellar pieces in the fraction is more than 15% and corresponds to the IV (the last) class of lamellar pieces content (from 25 to 35% of pieces) according to the classification of the standard [9]. So, the improving of its pieces shape to better classes with a lower content of lamellar grains (due to additional crushing with a small degree of size reduction) is advisable.

2. The yield of lamellar pieces for + 28 mm slot class subfraction is $\gamma_1 = 0.11 < 0.15$. Therefore, it is advisable to remove this subfraction from the fraction by using of slot sieves. So, only subfractions of slot classes -28 + 20 mm and -20 mm should be used for processing.

3. Let's determine the rational design and technological parameters of the crusher operational part using formulas (1) - (15).

The size of gap between the roll ledges is:

$$b = k_s s_{0,1} = 0.65 \cdot 0.028 = 0.018 \text{m} = 18 \text{ mm},$$

where $k_s = 0.65$.

The minimum value of the roll nominal diameter (by ledges) is:

$$D_{1,min} = \frac{s_{0,1} - b\sqrt{1+f^2}}{\sqrt{1+f^2} - 1} = \frac{0.028 - 0.018\sqrt{1+0.3^2}}{\sqrt{1+0.3^2} - 1} = 0.209 \text{ m.}$$

Let's take the diameter value:

$$D_1 = 0.26 \text{ m} = 260 \text{ mm.}$$

The maximum pitch value of roll ledges in axial direction is:

$$l_{max} = k_l d_{0,min} = 0.67 \cdot 0.040 = 0.027 \text{ m} = 27 \text{ mm},$$

where $k_l = 0.67$.

The minimum pitch value of roll ledges in axial direction is:

$$l_{min} = 2d_{dis} = 2 \cdot 0.005 = 0.01 \text{ m} = 10 \text{ mm},$$

where $d_{dis} = 0.005$ m.

The maximum radius of the roll profile ledges rounding is:

$$r_{1,max} = 0.1 d_{0,min} = 0.1 \cdot 0.04 = 0.004 \text{ m} = 4 \text{ mm}.$$

The minimum radius of the roll profile ledges rounding is:

$$r_{1,min} = 0.001 \text{ m} = 1 \text{ mm}.$$

In this case, we finally accept that:

- the pitch of the roll ledges arrangement is:

$$l = 0.015 \text{ m} = 10 \text{ mm};$$

- the radius of the roll profile ledges rounding is:

$$r_1 = 0.002 \text{ m} = 1 \text{ mm}.$$

The radius of the roll profile hollows rounding in this case is taken as follows:

$$r_2 = r_1 = 1 \text{ mm}.$$

The angle of the roll ledges sharpening for granite is taken equal to:

$$\alpha_{sh} = 90°.$$

The angle of inclination to the symmetry axis for the roll profile taper sections is:

$$\beta = 90° - 0.5\alpha_{sh} = 90° - 0.5 \cdot 90° = 45°.$$

The height of the roll profile (the span between the ledge and the hollow in radial direction) is:

$$h = 0.5l \cdot tan\,\beta - (r_1 + r_2)\frac{1 - cos\,\beta}{cos\,\beta} = 0.5 \cdot 10 \cdot tan\,45° - (1 + 1)\frac{1 - cos\,45°}{cos\,45°} =$$
$$= 4.2 \text{ mm} = 0.0042 \text{ m}.$$

The diameter of rolls by the bottom of hollows is:

$$D_2 = D_1 - 2h = 260 - 2 \cdot 4.2 = 251.6 \text{ mm} = 0.2516 \text{ m}.$$

The length of the roll working part is:

$$L = 0.7 D_1 = 0.7 \cdot 260 = 182 \text{ mm} = 0.182 \text{ m}.$$

The roll rotational speed is:

$$n = \frac{\upsilon}{\pi D_1} = \frac{4.5}{3.14 \cdot 0.26} = 5.51 \text{ s}^{-1} = 5.51 \text{ rev/min.}$$

The theoretical volume capacity of the crusher is:

$$Q = \mu b L \upsilon = 0.25 \cdot 0.018 \cdot 0.182 \cdot 4.5 = 0.0369 \text{ m}^3\text{/s} = 13.3 \text{ m}^3\text{/hr.}$$

The theoretical mass capacity of the crusher is:

$$Q_M = \rho_b Q = 1400 \cdot 0.00369 = 5.17 \text{ kg/hr} = 18.6 \text{ t/hr.}$$

4. Conclusions

1. The technique of calculating the parameters of the crusher with wave profiled rolls for processing of the narrow-sized fractions of crushed stone in order to reduce the content of lamellar pieces is developed for determining the rational parameters of the roll crusher operational part in order to improve the most efficiently the shape of pieces in crushing products.

2. Based on the above calculations, the advisability of complete or partial improvement of the pieces shape of the narrow-sized fractions of construction crushed stone is determined. The size of the gap between the rolls, the dimensions of the rolls, the geometric parameters of the wave profile of rolls, the roll rotational speed and the crusher output values are specified.

3. The area of the technique application is the calculation of parameters of the operational part of crushers with wave profiled rolls designed to improve the shape of pieces of the narrow-sized fractions of construction crushed stone made of hard rocks, which are used as filler in responsible concrete and asphalt-concrete products.

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About authors

Tytov Oleksandr Oleksandrovych, Candidate of Technical Sciences (Ph. D), Associate Professor, Associate Professor in Department of Engineering and Design in Machinery Industry, Dnipro University of Technology, Dnipro, Ukraine, tytov.o.o@nmu.one

Babii Kateryna Vasylivna, Doctor of Technical Sciences, (D.Sc), Senior Researcher, Deputy Director of the Institute, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, babiyev@i.ua

Sukhariev Vitalii Vitaliiovych, Candidate of Technical Sciences (Ph.D.), Senior Researcher in Department of Mechanics of Mineral Processing Machines and Processes, Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine (IGTM NAS of Ukraine), Dnipro, Ukraine, agnivik@ukr.net

МЕТОДИКА РОЗРАХУНКУ ПАРАМЕТРІВ ДРОБАРКИ З ХВИЛЬОВИМ ПРОФІЛЕМ ВАЛКІВ ДЛЯ ОТРИМАННЯ КУБОПОДІБНИХ ПРОДУКТІВ

Титов О.О., Бабій К.В., Сухарєв В.В.

Анотація. Метою даної роботи є розробка методики розрахунку дробарки з хвильовим профілем валків на основі аналітичних та експериментальних даних щодо дроблення міцних гірничих порід у дробарках такого типу. Наведено відомості щодо доцільності використання продуктів кубоподібної форми в якості заповнювачів для бетонів, акцентовано увагу на переваги такого підходу. Проаналізовано основні типи обладнання, що здатне виробляти кам'яні продукти з мінімальним вмістом лещадних шматків. Обґрунтовано вибір саме дробарок з хвильовим профілем валків для переробки вузьких фракцій щебеню як таких, що поєднують високу ефективність роботи із помірним зносом робочих поверхонь та низькою динамікою робочих режимів. Наведено алгоритм визначення параметрів дробарки, ґрунтуючись на теоретичних висновках та експериментальних даних з дрібного дроблення міцних гірничих порід з кар'єрів України на реальному зразку дробарки з хвильовим профілем валків. В якості вихідних даних взято гранулометричні характеристики вузьких фракцій за результатами розсіву матеріалу на круглих та щілинних ситах, долю лещадних шматків у вихідному матеріалі, коефіцієнт тертя матеріалу об робочу поверхню валків, окружна швидкість на виступах валків. На основі попередніх досліджень авторів, поступово визначені такі параметри дробарки, як розмір щілини між виступами валків, номінального діаметра валків, кроку розташування виступів валків в осьовому напрямку, радіуси заокруглення виступів та впадин профілю валків, кут загострення виступів валків, кут нахилу твірних конічних ділянок, висота профілю, довжина робочої частини валків, частота обертання валків, теоретична продуктивність дробарки. Також наведено модельний приклад розрахунку параметрів дробарки для переробки фракції граніту розміром від 70 до 40 мм із лещадністю 30%.

Зроблено висновки про те, що, по-перше, розроблена методика розрахунку параметрів дробарки з хвильовим профілем валків для переробки вузьких фракцій щебеню з метою зниження вмісту лещадних шматків, дозволяє визначити доцільність повного або часткового поліпшення форми шматків вузьких фракцій будівельного щебеню. По-друге, вона встановлює основні характеристики робочого органу дробарки та її приводу. По-третє, вона рекомендується для розрахунків параметрів робочого органу дробарок з хвильовим профілем валків, що призначені для покращення форми шматків вузьких фракцій будівельного щебеню з міцних гірничих порід, які використовують в якості наповнювача у відповідальних бетонних та асфальто-бетонних виробах.

Ключові слова: валкова дробарка, хвильовий профіль, методика розрахунку, лещадний шматок, вузька фракція, щілинне сито.