UDC 621.926.2

Analysis of roller crusher parameters for crushing process automation

Yevhen Mishchuk[1]

[1] Kyiv National University of Civil Engineering and Architecture,
Air Force Avenue, 31, Kyiv, Ukraine, 03037
mischuk.ieo@knuba.edu.ua, https://orcid.org/0000-0002-1888-3687

Received 27.03.2025; Accepted 28.04.2025
https://doi.org/10.32347/gbdmm.2025.105.0503

Annotation. Due to the significant energy costs in the process of manufacturing building materials, the need to reduce energy costs has become critical. One of the energy-consuming processes in crushing machines is the process of material destruction in the crushing chamber. Determining the energy costs that are incurred for material destruction, taking into account the physical properties of the material and creating conditions for the maximum rational application of loads in the crushing chamber is a pressing task. The study of the energy costs of a crushing machine is based on determining a number of processes and parameters that affect these processes. That is, the parameters of the mechanical mode of the crushing machine directly affect its energy efficiency. One of the types of crushing machines is roller crushers, the advantage of which is the simplicity and reliability of the design. Today, there is a tendency to replace medium and shallow cone crushers with HPGR roller crushers. The HPGR type crusher is used in the cement, iron ore and diamond industries. The main design parameters of roll crushers are: 1) angle of engagement; 2) frequency of rotation of the rolls; 3) productivity; 4) force between the rolls; 5) power The paper considers the crushing force of the roll crusher taking into account the physical properties of the material. The impact of the roll rotation speed on the friction coefficients that arise between the roll and the material, as well as between individual grains of the material, is assessed. The impact of the crusher roll rotation speed on the correction factor relative to the working environment is analyzed. The corresponding graphs are constructed, which reflect the limits of change of the corresponding coefficients at given roll rotation modes. Dependencies for determining productivity based on the efficiency factor and crushing force are considered. Dependencies for determining the angles of engagement for the fracture and compression zones are considered. To estimate the dimensions of the finished product, a dependence for determining the gap between the rolls is considered.

Keywords: roller crusher, friction coefficient, productivity, crushing force, roller diameter, distance between rollers, roller speed.

INTRODUCTION

Due to the significant energy costs for the manufacturing process of building materials, the need to reduce energy costs has become critical. One of the energy-consuming processes in crushing machines is the process of material destruction in the crushing chamber. As is known from numerous studies, a significant part of the energy in the process of material destruction is dissipated and only a small part of this energy is spent directly on material destruction [1],[2]. Therefore, determining the energy costs that are incurred for material destruction, taking into account the physical properties of the material and creating conditions for the most rational application of loads in the crushing chamber, is an urgent task. The urgency of this task is confirmed by the fact that research is currently underway to create methods for selective destruction [3],[4]. Research into the energy costs of a crushing machine is based on determining a number of processes and parameters that affect these processes. Thus, determining the parameters of the mechanical mode of the crushing machine directly affects its energy efficiency. Roll crushers are designed for medium and fine crushing of materials of different strengths. The working body of the roll crusher is a roll. Roll crushers with one and two rolls are common. 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 power supply along the entire length of the roll. A common roll crusher is a high-pressure roll crusher (HPGR). A roll crusher of this type was developed by Schoner [5],[6]. Such a crusher has high compression forces. Today, there is a trend of replacing medium and fine cone crushers with HPGR roller crushers. The HPGR crusher is used in the cement, iron ore and diamond industries. In high-pressure crushers, a large amount of material is held between the rollers and subjected to high pressure, as a result of which grinding can occur due to compression forces and due to interparticle destruction. In studies [7], [8] it was found that in the process of crushing the material due to the application of large compression forces to the material, the total energy spent on the destruction process will be less than in crushing machines where shock loads prevail.

GOAL AND PROBLEM STATEMENT

To assess and analyze the impact of mechanical mode parameters on the working processes of a roller crusher.

MAIN PART

The main design parameters of roll crushers are: 1) angle of engagement; 2) frequency of rotation of the rolls; 3) productivity; 4) force between the rolls; 5) power

Let us consider the scheme of material destruction in the working space of the rolls, Fig. 1. The crushing force F and the friction force caused by it act on the piece between the rolls from the side of the latter.

Based on the determined crushing energies based on the Kirpichev-Kik dependence, it is possible to determine the crushing work for one row of material with a diameter of *2r*:

$$A_{d.rc.} = \left(\frac{\sigma^2 \pi L \left(r^2 - e^2 \right)}{3E} \right) , \qquad (1)$$

The volume of crushed material in a roller crusher can be determined from the following relationship:

$$V = \left(\frac{2}{3} \right) \pi L \left(r^2 - e^2 \right) , \qquad (2)$$

where *L* – roll length; *2r* – diameter of the pieces of material fed into the crushing space of the roller crusher; *2e* – diameter of the finished product material pieces.

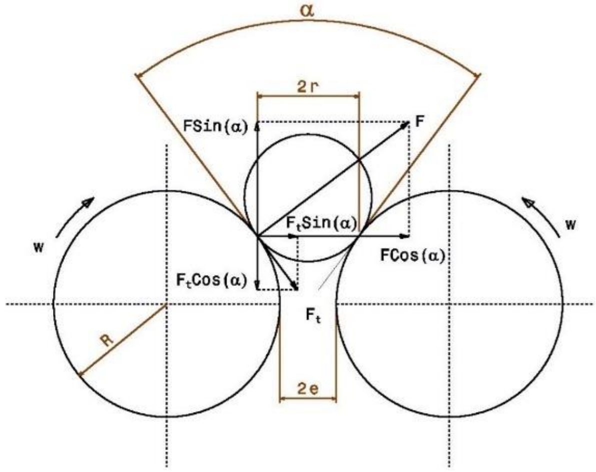


Fig. 1. Scheme for calculating the main parameters of a roller crusher

The force required to crush materials between the rolls is created by tightening the springs on which the moving roll rests:

$$F_{cr} = p\alpha RLk , \qquad (3)$$

where *p* – specific pressure taken from reference books depending on the diameter of the rolls, Pa; *α* – angle of capture, rad; *R* – roll radius, m; *L* – roll length, m; *k* – coefficient that takes into account the underloading of the rolls (*k*=0,2…0,6).

When the rolls capture pieces of material, the average crushing force causes friction forces - $F_{fr} = F_{cr}f$. Where f is the coefficient of friction.

The crushing force, which depends on the physical characteristics of the material for a roll crusher, can be determined based on the following relationship:

$$F_{c.rm.} = \left(\frac{\sigma^2 \pi L \left(r^2 - e^2 \right)}{3E s_n} \right) , \qquad (4)$$

where s_n = *2r-2e* – distance by which the rolls deform the material, m.

ISSN(online)2709-6149. Mining, constructional, road and melioration machines, 105, 2025, 85-90

The frequency of rotation of the rolls is given in the source [9] in the form of the following empirical dependence:

$$n_{\max} = 616m\sqrt{\frac{f}{100\gamma Dd}} \ , \qquad (5)$$

where f – coefficient of friction of the crushed material on the roll; γ – density of crushed material, kg/m^3; D – roll diameter, m; d – diameter of crushing material, m; m – coefficient that corrects for the crushing material, m=0.4…0.7 (larger coefficient values are accepted with correspondingly smaller values ρ, D, d).

An important parameter for roll crushers is the engagement angle, which in turn is determined based on the friction coefficient. The relationship between engagement angle and friction angle for roll crushers is written as – $f=tg\alpha$.

Thus, based on the condition of permissible limits of change in the friction coefficient – 0.2…0.3, the friction angle will take values in the range from 11^0 to 18^0.

If we consider the prism of the material that enters the space between the rolls, then it is necessary to additionally take into account the friction between the material particles and the change in this friction depending on the change in the speed of the rolls. The source [10] contains studies on the change in the kinetic coefficient of friction, which is determined as follows:

$$f_k = \left(\frac{(1+1.12n)}{(1+6n)} f \right) , \qquad (6)$$

If we take the value of the roll speed in the range from 10 to 200 rpm and the friction coefficient in the range of 0.2…0.3, then the dynamic friction coefficient will vary in the range of 0.040…0.060, which is presented in Fig. 2.

The productivity of roll crushers with smooth rolls is determined with the assumption that a continuous ribbon of finished product with a cross section $S=lL$ exits the crusher at a speed $v=\omega D/2$ [11]. Then the productivity, m^3/hour:

$$П_{в1} = 3600 L\omega lDk \, , \qquad (7)$$

where L – roll length, m; D – roll diameter, m; l – distance between rolls, m; ω – angular velocity of rolls, rad/s; k – coefficient that takes into account the degree of use of the width of the rolls and the loosening of the material (k=0.2…0.3 – for solid materials; k – 0.4…0.6 – for wet materials).

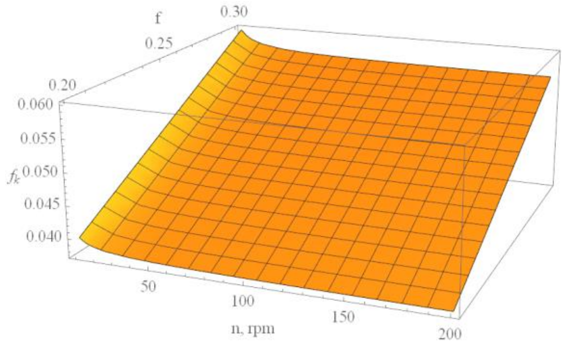


Fig. 2. Change in friction coefficients depending on the speed of the rolls

Таким чином ми бачимо, що важливу роль в отриманні необхідної продуктивності відіграє кут захвату між валками, коефіцієнт тертя, швидкість обертання валків. Продуктивність, яка розраховується на основі залежності (7) є теоретичною так як приймається, що матеріал безперервно подається в простір між валками, а продукт має форму безперервної стрічки із заданою шириною та товщиною.

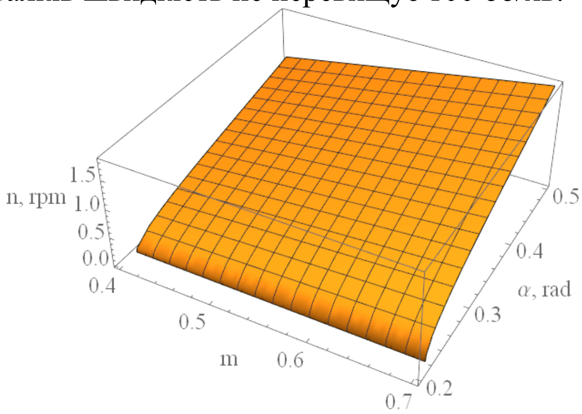
На основі геометрії валкової дробарки можна встановити залежність між вхідним та вихідним матеріалом, яка запишеться наступним чином:

$$\frac{D}{d} = \frac{cosa - \frac{l}{d}}{1 - cosa} \ , \qquad (8)$$

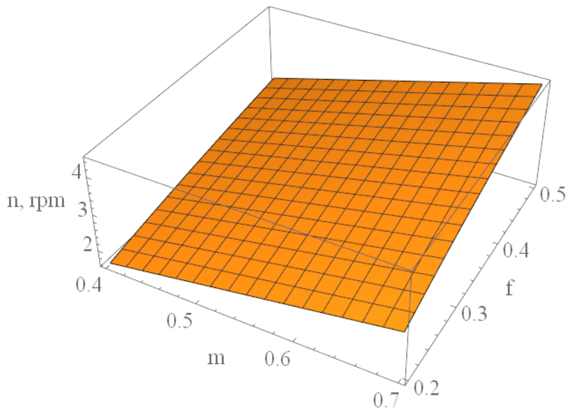
Розглянемо межі зміни частоти обертів валків в залежності від зміни кута захвату, коефіцієнту тертя, коефіцієнту m та діаметру матеріалу. Для аналізу приймемо насипну щільність матеріалу - γ = 1600 кг/м^3. Степінь дроблення більшості звичайних валкових дробарок з гладкими валками не перевищує 4 при дробленні порід середньої твердості та 10 для м'яких порід.

На основі вищезазначеного були побудовані відповідні графіки, які представлені на рис. 3. Значення кута приймалось в межах

10-30 градусів. Слід зазначити, що деяку невизначеність в залежність (5) вносить коефіцієнт m. З графіків видно, що оптимальні значення частоти обертів валків не виходять за межі 180 об/хв, хоча в цілому швидкість валкових дробарок з легкими валками може сягати 300 об/хв. При використанні великих валків швидкість не перевищує 100 об/хв.



a



b

Fig. 3. Graphs for determining the speed of rotation of rollers depending on: *a* – coefficient m and angle of capture; *b* – coefficient m and friction coefficient f.

The modified dependence for determining the productivity of a roller crusher is considered in [12]. The authors of the work try to approximate the value of the theoretical productivity to its real values by using the efficiency factor. The efficiency factor takes into account the voids between the particles and the change in the bulk density of the material when passing through the crushing chamber. The dependence has the following form:

$$\Pi_{в2} = 3600 \kappa L v \rho l\ , \qquad (9)$$

where к – efficiency coefficient, which takes values from 0.15 to 0.3, and depends on the distance between the rollers and the size of the material.

In high-pressure roller crushers of the HPGR type (roller press), due to the fact that destruction occurs by two mechanisms, the crushing chamber can be divided into two conditional parts: 1) the area where the particles are destroyed due to the capture by the rollers; 2) the area where the destruction occurs due to compression (compression zone). Based on this, in [13] it was proposed to determine two capture angles separately for two sections. The scheme for calculating the capture angles of the HPGR roller crusher is shown in Fig. 4.

Thus, the capture angle for the fracture zone is determined based on the dependence:

$$\alpha_1 = \arccos\left[1 - \left(\frac{d_{max}}{l} - 1\right)\frac{l}{1000D}\right], \qquad (10)$$

where d_{max} – maximum size of the fracture particle.

In turn, the angle of engagement for the compression zone will be determined as follows:

$$\alpha_2 = \arccos\left[1 - \left(\frac{\rho_к}{\rho_н} - 1\right)\frac{l}{1000D}\right], \qquad (11)$$

where $\rho_к$ – density of the material in the compressed zone, t/m^3; $\rho_н$ – density of the material in the fracture zone, t/m^3.

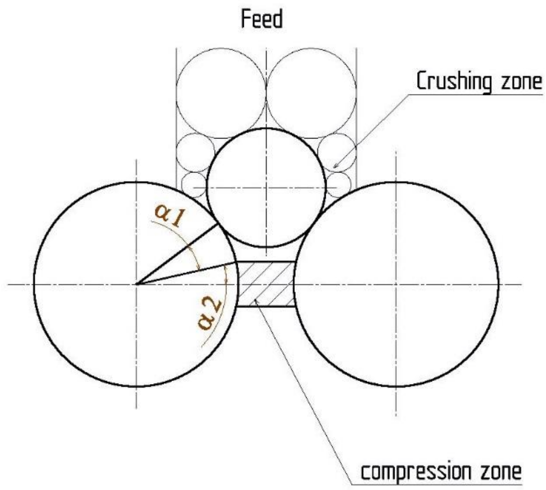


Fig. 4. Scheme for calculating the engagement angles of a roller crusher HPGR

To estimate the dimensions of the finished product material, an important parameter is the gap or distance between the rolls. In [14], a dependence is given for determining the working gap depending on the diameters of the rolls and the breaking force. This dependence has the following form:

$$l = \left(k_1 v^2 \left(\frac{2}{gD} \right) + k_2 v \sqrt{\frac{2}{gD}} + k_3 \right) \times \times \left(1 + k_4 \lg F_{cr} \right) D , \quad (12)$$

where k_1,k_2, k_3, k_4 – material became; F_{cr} – crushing force, N/mm; v – roller speed, m/s.

The speed for HPGR type roller crushers is determined based on the following statement: 1) for the diameter of the roll < 2 m, the speed should not be exceeded $v \le 1.35\sqrt{D}$; 2) for a roll diameter >2 m the speed is essentially proportional to the diameter $v \le D$.

In general, the performance of HPGR type roller crushers can be determined based on the dependencies for conventional roller crushers. However, in [14], a slightly different approach was proposed, which is based on specific productivity. In general, this dependency can be written as follows:

$$\Pi_{вз} = \Pi_{п} DLv\rho , \quad (13)$$

where ρ – density of the material fed into the crushing chamber; $\Pi_п$ – specific productivity, which is proportional to the ratio of the roller length to its diameter and is determined experimentally.

In another study [12], specific productivity is determined based on crushing force:

$$\Pi_п = k\left(1 + C \lg F^{п}{}_{cr}\right) , \quad (14)$$

where $F^{п}{}_{cr}$ – specific crushing force, which is determined based on the ratio F/(1000LD); k – coefficient that depends on the speed of the rollers; C - material constant.

The coefficient k in dependence (14) is determined experimentally, using the following dependence:

$$k = C_1 v^2 + C_2 v + C_3 , \quad (15)$$

where C_1 -C_4 – material constant.

Thus, the equation for specific productivity will be as follows:

$$\Pi_п = \left(1 + C \log F^{п}_{cr}\right)\left(C_1 v^2 + C_2 v + C_3\right) , \quad (16)$$

The study [14] noted that at crushing force values up to 6 N/m2 the impact of the specific productivity parameter on the overall productivity was insignificant. Under the conditions that the crushing force was constant, the speed had a negligible impact on the productivity. Rollers with a ribbed surface had increased productivity.

CONCLUSIONS

Based on the analysis performed, it can be noted that such parameters as the speed of rotation of the rolls, productivity, power are determined on the basis of empirical dependencies. When considering most of the parameters of the mechanical mode of the roll crusher, we encounter a number of coefficients that can be determined experimentally under appropriate operating conditions and machine designs. Here, it is especially worth noting the material correction coefficient and friction coefficients, which vary within wide limits. Further research into roll crushers consists in creating a scientifically sound methodology for calculating the parameters of the mechanical mode, taking into account the physical and mechanical properties of the environment.

REFERENCES

1. **Mishchuk Y., Mishchuk D., Kapusta O**. (2023). Mathematical modeling kinematics of double toggle jaw crusher . Girnichi, budivelni, Dorozhni Ta meliorativni Mashini, (102), 5–16. https://doi.org/10.32347/gbdmm.2023.102.0101
2. **Bearman R., Barley R., Hitchcock A.** (1991). Prediction of power consumption and product size in cone crushing. *Minerals Engineering*, *4*(11), 1243–1256. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/089268759190033Q.

3. **Bearman R.T.** (2019). Jaw and impact crushers. In P. B. Kawatra (Ed.), SME mineral processing and extractive metallurgy handbook. Society for Mining, Metallurgy, and Exploration, Inc., 367.
4. **Schönert K.** (1986). In P. Somasundaran (Ed.), Advances in mineral processing, SME/AIME, 19–31.
5. **Hudson J.A., Harrison J.P.** (1997). Engineering rock mechanics. Pergamon.
6. **Nazarenko I.I.** (1999). Mashyny dlia vyrobnytstva budivelnykh materialiv: Pidruchnyk [Machines for the Production of Building Materials: Textbook]. KNUBA, 488.
7. **Dunne, R. C.** (2019). Mineral processing & extractive metallurgy handbook. Society for Mining, Metallurgy & Exploration.
8. **Numbia, B. P., Zhang, J., & Xia, X.** (2014). Optimal energy management for a jaw crushing process in deep mines. Energy, 68, 337–348. https://doi.org/10.1016/j.energy.2014.02.100
9. **Ciężkowski, P., Maciejewski, J., & Bąk, S.** (2017). Analysis of energy consumption of crushing processes – comparison of one-stage and two-stage processes. Studia Geotechnica et Mechanica, 39(2), Article 12. https://doi.org/10.1515/sgem-2017-0012.
10. **Egbe, E. A. P., & Olugboji, O. A.** (2016). Design, fabrication and testing of a double roll crusher. *International Journal of Engineering Trends and Technology (IJETT), 35*(11).
11. **Haldar S.K.** (2018). Mineral exploration principles and applications. Elsevier, 378.
12. **Taggart, A. F.** (1998). Handbook of ore dressing. John Wiley & Sons Inc, 255-280.
13. **Couper J.R. Penney W.R., Fair J.R., Walas S.M.** (2005). Chemical process equipment: Selection and design (2nd ed.). Gulf Professional Publishing, 832.
14. **Wills B. A.** (1981). Mineral processing technology (2nd ed.). Pergamon Press, 617.

Аналіз параметрів валкової дробарки для автоматизації процесу дроблення

Євген Міщук[1]

[1] *Київський національний університет будівництва та архітектури*

Анотація. В зв’язку із значними затратами енергії на процес виготовлення будівельних матеріалів, критичною стала потреба в зменешенні енергозатрат. Одним із енергозатратних процесів в дробильних машинах є процес руйнування матеріалу в камері дроблення. Визначення затрат енергії, яка припадає на руйнування матеріалу з врахуванням фізичних властивостей матеріалу та створення умов по максимально-раціональному прикладені навантажень в камері дроблення є актуальною задачею. Дослідження енергетичних затрат дробильної машини ґрунтується на визначенні цілого ряду процесів та пара-метрів, які впливають на ці процеси. Тобто параметрів механічного режиму дробильної машини напряму впливають на її енергоефективність. Одним із типів дробильних машин є валкові дробарки, перевагою яких є простота та надійність конструкції. На сьогодні спостерігається тенденція заміни конусних дробарок середнього та мілкого дроблення на валкові дробарки типу HPGR. Дробарка типу HPGR використовується в цементній, залізорудній та алмазній промисловості. Основними розрахунковими параметрами валкових дробарок є: 1) кут захвату; 2) частота обертання валків; 3) продуктивність; 4) зусилля між валками; 5) потужність В роботі розглянута сила дроблення валкової дробарки з врахування фізичних властивостей матеріалу. Виконана оцінка впливу швидкості обертання валків на коефіцієнти тертя, які виникають між валком та матеріалом, а також між окремими зернами матеріалу. Проаналізовано вплив швидкості обертання валків дробарки на коефіцієнт поправки відносно робочого середовища. Побудовані відповідні графіки, які відображають межі зміни відповідних коефіцієнтів при заданих режимах обертання валків. Розглянуті залежності для визначення продуктивності, що ґрунтуються на факторі ефективності та силі дроблення. Розглянуті залежності для визначення кутів захвату для зони руйнування та стиснення. Для оцінки розмірів готового продукту розглянута залежність для визначення зазору між валками.

Ключові слова: валкова дробарка, коефіцієнт тертя, продуктивність, сила дроблення, діаметр валка, відстань між роликами, швидкість обертів роликів.