Improving the efficiency of the material grinding process

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Abstract. The paper provides an analysis of grinding systems used in the world practice, including the main technical solutions in the field of fine grinding of materials using a ball mill, and also presents indicators of their efficiency. It was found that the grinding systems of the partitioned grinding process with pre-grinding in a press-roll grinder showed the greatest efficiency from their use. However, today in various countries, free-standing units are used for deagglomeration of pressure-pressed semi-finished products, which require additional space for their placement and operation and maintenance costs. The authors describe the design of a press-roll unit with a device for breaking pressure-pressed materials, which allows reducing these costs, as it performs the following technological operations: volume-shear deformation of the material is carried out due to the conical profile of the main rolls; the compressed materials are disaggregated in the reverse direction of compression by means of additional rollers that have a reverse taper to the main rolls. A scientifically-based method for calculating the energy index of a new design of press roll unit is proposed, which allows for the energy calculation of these machines.

1. Introduction
Grinding materials using the sectional method, in which the coarse grinding stage is carried out outside the ball mill (BM) in a separate unit, is a very promising direction, while providing effective conditions for the destruction of materials. As, at the pre-grinding stage, aggregates are used that implement more efficient methods of destruction compared to the main grinding plant. Examples of such units are the press-roll type shredder (PRT), hammer mill (HM), cone inertia shredder (CIS), and others. Many prominent scientists Austin L, Klimpel R, Luckie P, Tavares L, de Carvalho R, Austin L., Shoji K., Bhatia V., Knieke C., Sommer M., Peukert W. are engaged in improving the efficiency of the partitioned grinding method [1-4].

Table 1 shows the energy indicators of grinding systems that are widely used in industry.

The analysis of specific indicators of these grinding systems indicates the feasibility of using the technology with pre-grinding in the press-roll unit. The use of this grinding technology reduces the specific power consumption by 30-40%, while increasing productivity by 20-45% [5-10, 11]. This effect can be explained by the results of studies on the grinding of materials of various strengths, which found that the energy spent on pre-grinding materials in the press-roll unit is 3.5 kWh/t, and in a ball mill with a similar fineness of grinding is - q = 6-10 kWh/t. For example, when grinding clinker to produce a product containing up to 30-35% of the fraction less than 80 microns, a press roll unit
under a pressure of 200 MPa consumes about 5 kWh/t of electricity, and in a ball mill about 10 kWh/t, which is 2 times less.

| Indicator                          | BM     | PRT-BM | CIS-BM  |
|------------------------------------|--------|--------|---------|
| Indexation                         | 4.2 x 16 | 1 x 0.8 | 1.8 x 14 | 1.75 | 3.8 x 14 |
| Specific power consumption, kWh/t  | 38.8   | 4.6    | 23.2    | 5    | 23.2    |

Table 1. Specific indicators of the main grinding complexes using a ball mill.

This energy saving is achieved by the high-pressure compression of mineral materials between the working bodies, which causes the grinding of not only the particles interacting with the surface of the rolls, but also those in the layer and in contact with each other.

2. Materials and methods

However, the material after processing it by pressure between the working bodies of the unit has the form of pressed filter cakes with maximum strength in the direction of force application (figure 1), which imposes special conditions for its effective deagglomeration and grinding.

Figure 1. The shape of the material after pressure treatment in PRU.

Today, the world uses technological schemes for partitioned grinding of materials, including a press-roll unit for pre-grinding, a hammer mill or other unit for disaggregating compressed material, and a ball mill for final grinding, operating in an open or closed grinding cycle [6,7, 9].

However, when using these technological solutions, the use of a separate unit for deagglomeration of compressed filter cakes requires additional space for its placement and costs for operation and maintenance.

We developed a design of a press-roll unit that allows implementing the processes of pressure grinding and disaggregation of compressed materials in one unit (Fig. 2).

The unit includes two main rolls 1 mounted on the frame, which have a conical profile, and a hopper 2. Deagglomerating rollers 3, located under the main rolls, have a smaller diameter and reverse taper with respect to them. This allows for the disaggregation of compressed materials in the opposite direction to pressing, which leads to a reduction in energy consumption for their destruction. The main rolls are connected to the rollers by means of rods that regulate the size of the gap between them, in proportion to its change between the main rolls [6, 8, 10]. This design of the PRU eliminates the accumulation of product before the deagglomerating rollers.
However, the lack of science-based recommendations for calculating the energy indicators of the unit for pre-grinding and deagglomeration hinders its widespread implementation in the industry.

When grinding materials in PRU, a number of technological operations are performed:
- volume-shear deformation of the crushed material - due to the use of a conical roll profile;
- disaggregation of pressed filter cakes in the direction of their lowest strength - due to additional rollers having the reverse taper of the main one.

For these operations, the drive power is consumed, which is determined by the following expression:

\[ N = \frac{N_1 + N_2 + N_3}{\eta}, \]

where \( N_2 \) - power spent on creating volume-shear deformation of the material, W; \( N_3 \) - power required to overcome the friction forces in the bearing units of the unit, W; \( N_1 \) - the power required for the disaggregation of the compacted filter cakes, W, \( \eta \) - efficiency.

The power spent on the destruction of the source material \( N_2 \) depends on the torque \( M_r \) required for grinding the materials and the moment of friction \( M_s \) that occurs in the roll supports.

The power spent on grinding the material is equal to:

\[ N_2 = M_r \omega, \]

where \( M_r \) – the resulting moment that occurs between the conical rolls when grinding the material, Nm; \( \omega \) - angular speed of rotation of the rolls, rad/s.

The value of the resulting moment, according to the calculation scheme Fig. 3, can be written as follows:

\[ M_r = 2 \frac{F}{2} R_{sr} = FR_{sr}, \]

where \( F/2 \) - circumferential force acting on the average roll radius \( R_{sr} \).

The circumferential force is determined by the following expression:

\[ F = 2 P_\Sigma \sin \gamma_n, \]
where $P_\Sigma$ – total spacer force acting between the rolls, N; $\gamma_n$ - the value of the neutral angle, deg.

The total spacer force is determined by the equation:

$$P_\Sigma = qBR_{sr} \gamma_n \cos \alpha,$$

(5)

where $q$ – specific grinding pressure, N/m$^2$, $B$- roll width, m, $\alpha$ - the angle of inclination of the working surface of the rolls.

Assuming that $\sin \gamma_n \approx \gamma_n$, as the angle is very small, we have the following expression:

$$N_2 = q\omega BR_{sr}^{2} \gamma_n^{2} \cos \alpha.$$

(6)

**Figure 3.** Scheme for determining the resulting moment.

The power required to overcome the friction forces in the roller supports can be determined by the following equation:

$$N_2 = 2\pi d \Theta_r f_k n,$$

(7)

where $d$ – the size of the diameter of the support part of the roll, m; $\Theta_r$ – total force resulting from the pressure between the rolls and the weight of the roll, N, $f_k$ - the coefficient of rolling friction, $n$ - the number of the roll turns, s$^{-1}$.

The value of the total force is determined by the following equation:

$$\Theta_r = \sqrt{P_\Sigma^{2} + G_b^{2}},$$

(8)

where $G_b$ - force arising from the weight of the roll.

The drive power expended on the disaggregation of the pressed plates depends on the maximum deagglomeration force $F$, the value of which depends on the width of the rollers $b$, and the compressive strength of the pressed plates $G$, as well as the angular speed of rotation of the rolls, equal to $\omega = 2\pi n$.

$$F = \mu b G \sin \beta,$$

(9)

where $\mu$ - coefficient depending on the density of pressed filter cakes and material properties, $\beta$ - maximum force angle between the rollers, deg.

Then the amount of torque is determined by the following expression:

$$M_1 = 2 \frac{F}{2} r_{sr} = F r_{sr},$$

(10)

where $r_{sr}$ - the average radius of the conical rollers, m.
Thus, the method proposed above allows calculating the engine power required for the implementation of the following technological operations in one unit:
- volume-shear deformation of materials due to the conical profile of the main rolls;
- disaggregation of compressed materials in the reverse direction of compression due to additional rollers that have an inverse taper with respect to the main rolls.

3. Summary
Thus, as a result of the analysis of the main technical solutions of grinding systems that work in conjunction with a ball mill and are widely used in world practice, it showed high efficiency from the use of a partitioned grinding process with pre-grinding in a press-roll unit. However, today in the world for the deagglomeration of pressure-pressed filter cakes between PRU rolls, free-standing units are used, the installation of which requires additional production space and operating and maintenance costs.

The developed new design of the press roll unit allows reducing these costs. When grinding materials in PRU with a device for deagglomeration of compressed materials, a number of technological operations are performed: volume-shear deformation is performed due to the conical profile of the main rolls and the compressed materials are disaggregated in the opposite direction to pressing due to additional rollers that have an inverse taper in relation to the main ones.

A scientifically-based method for calculating the energy index of a new design of a press roll unit is proposed. This method allows calculating and designing these machines, which will speed up their introduction into the industry.

4. References
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