The grinding bodies movement dynamics study in a ball mill equipped with energy-exchanging devices

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Abstract. The article deals with the issues related to energy saving during grinding in a ball mill equipped with energy exchange devices, pre-milled in a press-roller grinder. The bulk solids movement analysis in a ball mill at different locations in the energy exchange devices drum is presented.

Introduction
The results of the studies showed that the crushed slag in PRG after pressure treatment between the rollers differs from the initial one (Figure 1a). It has an anisotropic texture with maximum strength in the force application direction and the compressed tape product form. Its particles have a microdefect structure (Figure 1 b), which requires special conditions for its deagglomeration and grinding in the BM.

![Figure 1. View on the slag: a in the initial material; b - deformed in PRG](image)

Studies have shown that it is advisable to expose the preliminarily ground material to short-term shock-shear effects in the first chamber of the mill. Then the material is crushed in the second chamber. Under such grinding conditions it is possible to create a double action partition (DAP) and an inclined segment (IS) in the BM, equipped with energy-exchanging devices (EED). However,
depending on the install energy-exchanging devices scheme in the drum the grinding bodies dynamic action mode on the material being ground changes [1, 2].

It is necessary to determine the EED scheme. In order to determine the operation modes of grinding load with different installation diagrams and the EED relative position, the studies were conducted on a ball mill model with a transparent casing with a size of $\varnothing 0.1 \times 0.5$ m (Figures 3, 4).

![Fig. 2. A slag particle with a microdefect structure after pressure treatment in PRG: a - ($\times 10$); b - ($\times 80$)](image)

As a result of the research, it was found that the grinding bodies dynamic effect nature in the BM is significantly influenced by the EED relative position both in the longitudinal and in the mill housing cross section. [3, 4]

ES is installed at the discharge end of the mill drum tilted to the bottom, and its major axis coincides with the larger axis of the NMP (Figure 3a). Thus, as a result of using the EED installation scheme there is a simultaneous effect on the grinding load with an interval of $360^\circ$.

This leads to the grinding media concentration in the middle of the mill second chamber, which will adversely affect the grinding process efficiency.

**Main part**

When the ES rotates relative to the NMP at an angle of $180^\circ$ (the displacement of their major axes makes an angle of $180^\circ$), the alternating effect of the EC on the grinding medium is alternated. It creates greater mobility of the grinding bodies and their movement with their concentration in the NMP (Figure 3, b). [5]

This EED installation scheme should contribute to the pre-ground materials grinding process intensity in the second mill chamber.

However, the IS installation, inclined to the discharge bottom, leads to the load seizure and raise it to a great height, which partially creates a waterfall operation mode. Such scheme of EED installation will reduce the ball mill second chamber efficiency and may cause damage to the grinding bodies. Changing the inclination angle of the inclined segment to the opposite, setting it at an angle of inclination from the discharge bottom (Figure 3, c), leads to the “waterfall effect’s” disappearance in the second mill chamber. Such an IS arrangement does not raise the grinding bodies to a height, but only increases its impact on it in the longitudinal direction. It makes possible to create an intense shear effect on the material being ground.

A change in the IS rotation angle relative to a double action partition at an angle different from $180^\circ$ (for example, $90^\circ$ or $270^\circ$) (Figure 3, d) leads to a partial concentration of the grinding medium in the center of the second chamber. This is due to the mutual imposition of impulses from DAP and IS, which will adversely affect the efficiency of the grinding process materials. [6]
Installing an inclined DAP will provide a shock-abrasive effect of the grinding load on the material to be ground in the first chamber of the mill, and controlling the magnitude of the impulse created by it when the angle of inclination changes makes it possible to provide for the presence of horizontal sections of the partition \( h_1, h_2 \) (Figure 3).

Thus, our grinding bodies movement nature studies in a BM equipped with energy-exchanging devices have shown that the grinding bodies operation mode largely depends on the installation scheme and the relative position of the double action partition and the inclined segment. A rational EED installation scheme in the mill drum when grinding slags previously crushed in PRG and having an anisotropic texture and commodity form in the form of pressed plates, and their particles - microdefect structure is the scheme (Figure 3, c). At this scheme the energy-exchanging devices joint action makes it possible to strengthen its force effect in the longitudinal direction. It makes possible to create an intense crushing and shear effect of grinding bodies on the material being crushed in the second unit’s chamber.

However, the IS inclination angle value has a significant impact on the output indicators of the ball mill operation. In order to establish their rational parameters, we conducted the experimental studies.

An analysis of the graphical dependence built on the experiment results (Figure 4) \( Q, N, q = f(\phi_2, \alpha) \) showed that when the angle of inclination \( \phi_2 \) changes from the vertical axis of the mill (\( \alpha = 0^\circ \) ...
0°) by an angle $\alpha = -30^\circ$ (equal to 0.53 radians) from the bottom of the mill there is an increase in the reduced capacity from $Q = 158 \, \text{kg/h}$ to $Q = 159.5 \, \text{kg/h}$ – by 3.9%.

The specific energy consumption when $\alpha$ is changed in this range ($0^\circ$…$-30^\circ$) is decreased to an extremum $q = 23.0 \, \text{W h/kg}$. [7]

A further increase in the ES inclination angle to $\alpha = -48.2^\circ$ leads to the increase in the specific energy consumption and a more substantial increase in $N$ by 5% ($N = 4.2 \cdot 10^3 \, \text{W}$ to $N = 4.4 \cdot 10^3 \, \text{W}$). This leads to an increase in the specific energy consumption from $q = 23.0 \, \text{W h/kg}$ to $q = 23.7 \, \text{W h/kg}$ (by 3%).

This is explained by the fact that the ES tilting to the discharge bottom of the mill at an angle $\alpha = 48^\circ$ leads to a mixed grinding bodies operation mode in the second mill chamber, as a part of the grinding load is captured by the ES and is raised to great grinding mode, instead of the desired cascade.

a)

Figure 4. The EED inclination angle influence on $Q$, $N$, $q$ at the grinding chambers different loading values of the second chamber: $(\phi_1 = 0.16; \xi = 0^\circ; l_1 = 0.6)$
This is explained by the fact that the ES tilting to the discharge bottom of the mill at an angle $\alpha = 48^\circ$ leads to a mixed grinding bodies operation mode in the second mill chamber, as part of the grinding load is captured by the ES and is raised to great grinding mode, thereby implementing the waterfall grinding mode, instead of the desired cascade.

At the same time, despite the fact that a great job of grinding work is being done, this does not lead to a significant increase in the reduced performance $Q$ (from $Q = 159.5 \, \text{kg} / \text{h}$ to $Q = 160.2 \, \text{kg} / \text{h}$). In this case, the specific energy consumption increases more significantly from $q = 23.0 \, \text{W} \cdot \text{h} / \text{kg}$ to $q = 25.5 \, \text{W} \cdot \text{h} / \text{kg}$, i.e. by 10.8%, which is due to a more significant increase in $N$.

Increasing the angle of inclination of the ES to the discharge side of the mill to $\alpha = 48.2^\circ$ leads to an increase of $N$ by 4.8% ($N = 4.2 \cdot 10^3 \, \text{W}$ to $N = 4.4 \cdot 10^3 \, \text{W}$), with a slight increase in $Q$ (with $Q = 159.5 \, \text{kg} / \text{h}$ to $Q = 160.2 \, \text{kg} / \text{h}$), which affects $q$ from $q = 23.7 \, \text{W} \cdot \text{h} / \text{kg}$ to $q = 25.5 \, \text{W} \cdot \text{h} / \text{kg}$ (by 6.7%). [8,9]

It follows from the above-mentioned that when grinding pre-ground slag in PRG with an anisotropic texture, the most rational is the ES inclination angle equal to 30° (0.53 radians), and the ES must be tilted from the mill discharge bottom. This is explained by the fact that this arrangement of the ES contributes to the intensive crushing and wear effect of the grinding load on the material being crushed. The cascade mode of the mill in the fine grinding chamber is not disturbed.

An increase in the load ratio of the grinding bodies of the second chamber from $\varphi_2 = 0.269$ to $\varphi_2 = 0.331$ leads to a proportional increase in the reduced performance and drive power consumption, which slightly affects the value of specific energy consumption. This indicates that the enhancement of crush-shear deformation has a positive effect on the slag with an anisotropic texture grinding.

**Summary**

The equipment mills with EED provides the grinding aggregates with the following advantages and allows:

1. It makes possible to change the grinding bodies dynamic effects mode on the material along the mill length, depending on its physical and mechanical properties;
2. To create intensive internal material recycling and the combination of two processes in one grinding unit (for example, grinding and mixing);
3. To increase the useful volume of the mill due to the grinding bodies stagnant zones EED destruction and the creation of an intensive transverse-longitudinal movement of the grinding medium;
4. To reduce the grinding bodies mass by 10...15% and increase the grinding unit productivity by 20...25%;
5. It makes possible to reduce the specific energy consumption by 10...15%;
6. To protect frontal armor plates and discharge grids from intensive wear.

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