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Research kinetic of motion of milling bodies in ball mill, outfit heat-exchange unit and calculation of its energy performance

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Abstract. The article considers topical issues of energy saving in cement production with the use of a technological grinding complex, which includes a press roller grinder and a ball mill. Rational conditions of grinding are proposed for pre-shredded material through the installation of blade energy exchange devices (BEED) in the mill drum. The loading level in the first chamber varies periodically depending on the drum rotation angle, equipped with BEED. In the zone of BEED's active action, there is a "scooping" of a part of grinding bodies together with crushed material, raising them to a height and giving them a longitudinally transverse movement, which is different from movement created in the mill without BEED. At the same time, additional work that consumes engine power is being done. A technique is proposed for calculating the additional engine power consumption of a mill, equipped with a BEED. This power is spent on creating a longitudinal-transverse motion of grinding bodies and its first and second chambers in areas of active influence of the BEED. Comparative analysis of results obtained experimentally and calculations of proposed equations show a high convergence of results. These analytical dependencies may be interest to Russian and foreign organizations that carry out their activities in the field of design and manufacture of cement equipment, as well as to cement producers.

1. Introduction

In the production of binding materials, various building mixtures and products, one of the most energy-intensive processes is process of crushing and grinding raw materials, for which about 10% of the world's electricity is consumed. At the same time the power consumption significantly increases with the dispersion of obtained product.

It is known [1-2] that the power consumption is: for crushing of materials - 10-21 J/g, for fine and superfine grinding - 360-3600, J / g. Therefore, studies, aimed at improving the technology of grinding and equipment to reduce the energy intensity of the process, are relevant.

The annual volume of the cement production in the world increase and it is more than 2.5 billion tons per year. The grinding process of raw materials and cement materials, mainly in ball mills, consumes 40 to 70% of the total power of the process [3-4].

Scientists and practitioners, both in Russia and abroad, were engaged in developing new and improving the efficiency of existing grinding equipment [5-8]. They developed an energy-saving technology for obtaining cement in a grinding complex consisting of two aggregates of a press roller shredder and a ball mill (PRG-CMM) [9-10].

2. The main part

As a result of the research it is established that material crushed in PRG after its treatment by the pressure between rollers differs significantly from the initial one. It has the form of compressed plates, and its particles have micro-defect structure that requires special conditions for their grinding (Figure 1).

a

b

Figure 1. Clinker: a - initial material, b – material after milling in a PRG.

According to research results material crushed in PRG should be subjected to a short-term impact in the first chamber of the mill for deagglomeration of compressed tape and crushing-abrasion of the grinding load in the second chamber for final grinding. Such conditions of grinding materials can be obtained in a ball mill with blade energy exchange devices (BEED): blade double action (BDA) and the blade elipsis segment (BES).

In order to determine operating modes of the grinding load for various schemes of the BEED, studies were carried out on a model of a ball mill with a transparent body with size ∅ 0,1×0,5m (Figure 2 a-d) of the small innovative enterprise "Center for Energy-Saving Technologies and Complexes" on the basis of the innovative business incubator of the Belgorod State Technological University named after V.G. Shoukhov in the framework of state support of innovation entrepreneurship of young scientists of Russian universities.

As a result of the research it was found out that the nature of the dynamic impact of grinding bodies in CMM is significantly influenced by the relative location of the BEED both in longitudinal and in cross section of the mill body.

So, if BES is installed at the unloading end of the mill drum and inclined towards the bottom, its major axis coincides with the larger axis of the BDA (Figure 2a), then their simultaneous action occurs at an interval of 360 ° through the grinding load. This leads to the concentration of grinding media in the middle of the second chamber, that will negatively affect the efficiency of the grinding process.

When the BES rotates relative to the BDA at an angle of 180 ° (the displacement of their large axes makes an angle of 180°), this leads to alternate exposure of the BEED to the grinding load, that leads to greater mobility, movement and concentration of the BDA and BES (Figure 3b). This scheme of BEED installation should contribute to the intensity of the grinding process of pre-crushed materials in the second chamber of the mill.

However, the installation BES, sloping to the unloading bottom, leads to the capture of the cilpel load and lifting it to a higher altitude. This leads to a partial waterfall mode and reduces the effectiveness of its work in the second chamber. The change in the angle of BES inclination by the opposite one (Figure 3c) leads to the disappearance of the "waterfall effect" in the second chamber of the mill, because this location of the BES does not raise the grinding environment, but only intensifies its impact on it in the longitudinal direction that has a positive impact on the grinding material.

When one changes the angle of the BES relative to the BDA angle different from 180^0 (e.g., 90˚ or

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270^0) (Figure 3d) leads to a partial concentration of the grinding environment in the center of the chamber. This is due to the mutual imposition of pulses from effects of BDA and BES, which will also have a negative impact on the efficiency of the grinding process of materials.

The installation of BDA will ensure a shock-abrasive effect of the grinding load on the grind material in the first chamber of the mill. Controlling the magnitude of the pulse from the BDA, in addition to its angle of inclination, makes it possible to ensure the availability of horizontal sections of the partition.

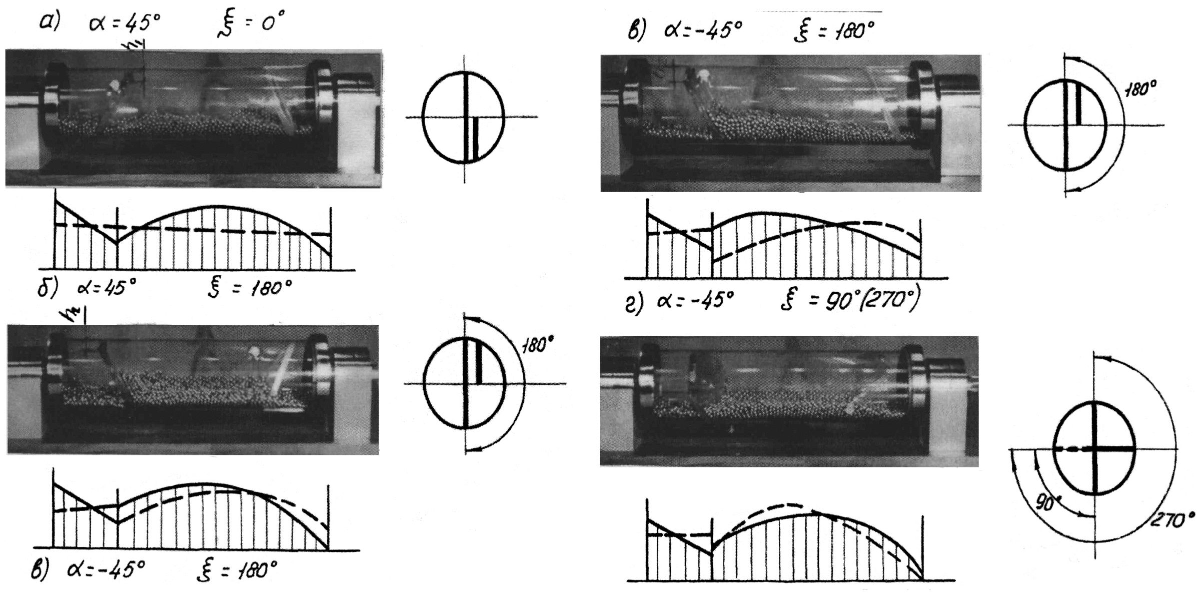

Figure 2. Schemes for installing BEED and diagrams of motion of grinding bodies.

Thus, studies of the character of grinding bodies motion in CMM equipped with BEED show that the operating mode of the grinding load depends to a large extent on the layout of the installation and the relative location of the BDA and BES. The rational scheme for installing the BEED in the drum mill with the grinding of materials pre-crushed in PRG is the scheme (Figure 2c) whereby in the first chamber of the mill it is carried out abrasive grinding action of grinding bodies, and in the second - crush-grinding process.

The conducted studies show the installation of BEED in the form of BDA, and BES in the drum of the ball mill makes it possible to intensify the movement of grinding load. The loading level in the first chamber varies periodically depending on the drum rotation angle. In the zone of BEED active influence, there is a "scooping" of a part of grinding bodies together with the material to be crushed, raising them to a height and giving them a longitudinally transverse movement in the mill without BEED (Figure 3). At the same time, additional work is being done, which requires the additional engine power. And the absence of a scientifically grounded method of calculating its value for mills equipped with BEED slows down their introduction into the industry.

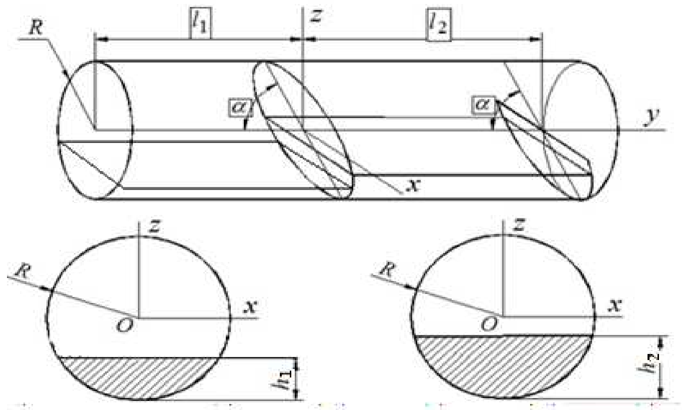

Figure 3. The scheme of installation of BEED in the drum ball mill.

Additionally, the consumption of mill power is related (compared to mills with vertical partitions) to the movement of the center of mass of the grinding bodies along the axis of the drum of the mill through the influence on the grinding load in the longitudinal direction of BDA and BES.

Power *N* for a certain period of time *T* is calculated by the formula:

$$N = \frac{A}{T}, \tag{1}$$

where *A* - the amount of work done during the same time period *T* .

For a period of time *T*, let us take the time of one rotation of the mill's drum; if the mill makes *n* rotations per minute, then one rotation is performed in a time equal to:

$$T = \frac{1}{n} \text{ min} \tag{2}$$

or

$$T = \frac{60}{n} \text{ sec.} \tag{3}$$

In this case:

$$n = \psi\, n_{cr}, \tag{4}$$

where ψ [Psi] – the relative frequency of rotation, n_{cr} – the critical frequency of rotation.

In that:

$$n_{cr} = \frac{30}{\pi}\sqrt{\frac{g}{R}}, \tag{5}$$

where g = 9.81 m/s^2 – acceleration of gravity, *R*– radius of the mill drum, then formula (3) can be written in the following form:

$$T = \frac{2\pi\sqrt{R}}{\psi\sqrt{g}} \text{ sec}. \tag{6}$$

During one rotation of the mill's drum, the center of mass of the grinding charge in each chamber will move from one extreme position to the other and back again. For the first chamber, the movement of the center of mass of the load in one rotation of the mill's drum is determined by the formula:

$$S_1 = 2\left|y_c - y'_c\right|. \tag{7}$$

According to [6], y_c and y'_c are calculated, respectively, by formulas:

$$\tilde{y}_c\tilde{V}_1 = -\frac{\lambda_1^2}{2}\left(\chi_1\sqrt{1-\chi_1^2} + \arcsin\chi_1 - \frac{\pi}{2}\right) - \frac{2\lambda_1 \mathrm{ctg}\alpha}{3}\left(1-\chi_1^2\right)^{\frac{3}{2}} + ... \\ + \frac{\mathrm{ctg}^2\alpha}{8}\left(\chi_1(1-2\chi_1^2)\sqrt{1-\chi_1^2} - \arcsin\chi_1 + \frac{\pi}{2}\right). \quad (8)$$

$$\tilde{y}'_c\tilde{V}''_1 = -\frac{\lambda_1^2}{2}\left(\chi'_1\sqrt{1-\chi_1'^2} + \arcsin\chi'_1 - \frac{\pi}{2}\right) + \frac{2\lambda_1 \mathrm{ctg}\alpha}{3}\left(1-\chi_1'^2\right)^{\frac{3}{2}} + ... \\ + \frac{\mathrm{ctg}^2\alpha}{8}\left(\chi'_1(1-2\chi_1'^2)\sqrt{1-\chi_1'^2} - \arcsin\chi'_1 + \frac{\pi}{2}\right). \quad (9)$$

Moving the center of mass of the load for one rotation of the mill drum in the second chamber is determined by the formula:

$$S_2 = 2\left|y_{c2} - y'_{c2}\right|, \quad (10)$$

Calculating y_{c2} and y'_{c2} according to (4) is determined by formulas:

$$\tilde{y}_{c2}\tilde{V}_2{}' = \frac{\mathrm{ctg}^2\alpha}{8}\left(\chi_2\left(2\chi_2^2 - 1\right)\sqrt{1-\chi_2^2} + \arcsin\chi_2 - \frac{\pi}{2}\right) - -\frac{\lambda_2^2}{2}\left(\chi_2\sqrt{1-\chi_2^2} + \arcsin\chi_2 - \frac{\pi}{2}\right). \quad (11)$$

$$\tilde{y}'_{c2}\,\tilde{V}''_2 = \frac{\lambda_2^2}{2}\left(\frac{\pi}{2} - \arcsin\chi'_2 - \chi'_2\sqrt{1-\chi_2'^2}\right) + \frac{2l_2 \mathrm{ctg}\alpha}{3}\sqrt{\left(1-\chi_2'^2\right)^3}. \quad (12)$$

Since the work is done by the friction force, then:

$$A = \left|F_{fr}S\right| = F_{\mathrm{fr1}}S_1 + F_{\mathrm{fr2}}S_2\,. \quad (13)$$

In its turn:

$$F_{\mathrm{fr1}} = f\,G_1 = f\,M_1 g = f\,g\,\gamma V_{1load} = f\,g\,\gamma\phi_1 V_1, \quad (14)$$

where f – coefficient of sliding friction grinding load on the body of the drum mill; G_1 – weight of the grinding load in the first chamber; M_1 – mass of the grinding load in the first chamber; γ [gamma] – bulk weight of grinding load; V_{1load}– volume of the grinding load in the first chamber; φ_1 [fi] – coefficient of loading grinding bodies of the first chamber; V_1 – volume of the first chamber.

A similar formula holds for the second chamber:

$$F_{\mathrm{fr2}} = f\,G_2 = f\,M_2 g = f\,g\,\gamma V_{2load} = f\,g\,\gamma\phi_2 V_2 \quad (15)$$

Comparative results are obtained experimentally and calculated with the following input parameters: the radius of the mill drum is R = 0.5 m; the length of the first chamber is l_1 = 0.65 m; the coefficient of loading of the first chamber is φ_1 = 0.18; the length of the second chamber is l_2 = 1.3 m; the coefficient of loading of the second chamber is φ_2 = 0.3; the coefficient of sliding friction is f = 0.4; bulk weight of grinding load is γ = 4 550 kg/m^3; the angle of inclination of the BDA and BES to the axis of the mill drum is α = 60°; relative rotational speed of the mill drum is ψ = 0.76 (corresponds to 45.5 min^{-1}). This shows that the difference between experimentally obtained and calculated data does not exceed 10%. With indicated values of the input parameters, the additional power consumption, obtained by calculation, was as follow: for the first chamber – 62.2 W; for the second chamber – 441.0 W; in general for the mill – 503.2 W, experimentally obtained – 545 W.

3. Conclusions

Thus, the installation of the energy exchange device in the mill drum makes it possible to intensify the operation of the grinding load that is indicated by the value of the additional power consumption of the drive, and equations (10) and (11) obtained analytically make it possible to calculate the value of the additional power consumed by the mill, equipped with the BEED, and reflect the real process with sufficient accuracy.

The comparative analysis of the experimentally obtained data and calculation shows that the difference between them does not exceed 10%.

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