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Analysis of the efficiency of the grinding process in closed circuit ball mills

Valery I. Telichenko[1], *Rashid R.* Sharapov[1*], *Svetlana Y.* Lozovaya[2] and *Vladimir I.* Skel[1]

[1]Moscow State University of Civil Engineering, Moscow, Russia
[2]Belgorod State Technological University named after V.G. Shukhov, Belgorod, Russia

Abstract. Ball mills for fine grinding cement clinker and additives are widely used around the world. To improve the efficiency of a ball grinding the ball mills are transferred in closed circuit with air-separators of various designs. In the article the analysis of existing grinding circuits on the basis of closed circuit ball mills made. Introduced a summary measure that allows to evaluate the performance of the grinding system according to various criterias. The conclusion about the prospects of data systems grinding when grinding to ordinary cement, in comparison with the grinding systems based on other principles of grinding.

1 Introduction

Technological system of grinding (TSG) in a closed circuit on the basis of the ball mill (BM), worldwide widespread [1-8]. With the development of dynamic separators (DS) of the third generation dramatically increased the energy efficiency of grinding systems and TSG "BM–DS" began to occupy a dominant position. In Fig. 1 shows the traditional scheme with a return of coarse in the beginning of the process to the I camera. They provide cement production parameters grain structure: n = 0,9...1,1; d' = 10...25 μm, which corresponds to the values of specific surface S ≈ 3000...6000 cm^{2}pg [9]. The energy specific consumption in this case is 35...80 kWhpt. TSG "BM–DS" equipped with ball mills with the diameter D = 3.6...6 m and a length L = 12...16 m with a power level of a single mill 3000...10 000 kW [10].

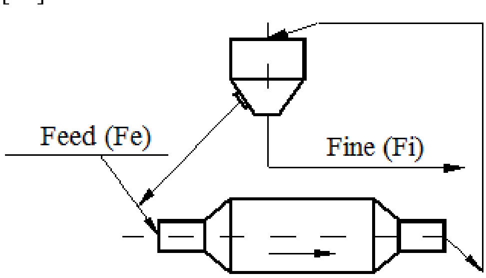

Fig. 1. Technological scheme of grinding "BM–DS"

* Corresponding author: ptdm_zavkaf@mail.ru

One of Russia's largest ball mill in size 4,6×14 m, with an power installation is 4250 kW [11] when the specific surface of the finished product in 3230 cm^2pg reached capacity 126 tph. In this case the specific energy consumption was 35 kWhpt. Metal consumption in the production output amounted to 6.9 tp(tph) at a specific volumetric productivity of 0.62 (tph)pm^3. An important indicator characterizing the efficiency of grinding are the specific energy consumption per unit specific surface area (qpS, kWhpm^2). For this grinding unit this parameter is $1.08 \cdot 10^{-4}$ kWhpm^2.

Experience of operation of ball mills suggests that transfer of mill in closed circuit with a separator of the dynamic type, or modernization of a closed circuits replacement of traditional separators to dynamic is an essential reserve to increase not only the efficiency but also the quality of the end product.

The company Christian Pfeiffer (Germany) carried out a reconstruction of TSG with ball mill open and closed circuits [12] with the installation in all cases the dynamic separator. When transferring to closed circuit a mill size 2.6×13 m at a constant quality cement (3000 cm^2pg) capacity grinding unit was increased from 25 to 38 tph while reducing the specific consumption of electricity from 41.6 to 29.3 kWhpt. The parameter qpS is reduced from 1.39 to $0.98 \cdot 10^{-4}$ kWhpm^2. Due to the more intense the aspiration of the mill and cooling separator air temperature of the finished product decreased from 120..130 °C up to 70...80 °C. The metal content of products made up of 8.95 t/(tph) at a specific volumetric productivity equal to 0,63 (t/h)pm^3 [12].

Replacement of outdated disign of the separator for ball mill 4×13.5 m allowed due to the optimization of the grain composition with constant brand of cement (CEM I 42.5 N) is to reduce the specific surface of the finished product with a 4670 to 3800 cm^2pg, which in turn allowed for a constant power consumption to improve the performance of the grinding unit 57 to 86 tph while reducing the specific consumption of electricity from 51.9 to 37 kWhpt. The parameter qpS also decreased from 1.11 to $0.97 \cdot 10\text{-}^{4}$ kWhpm^2. The power density of cement grinding amounted to 21.93 kWpm^3 and the temperature reduction of crushing products made from 105 to 60°C. The metal content of products amounted to 7.7 t/(tph) at a specific volumetric productivity equal to 0.6 (t/h)pm^3.

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Improving inner mill accessory (lining mill partition, the output diaphragm and composition of the grinding media) also allows to improve the process of grinding in a closed circuit ball mill. However, the performance of the grinding unit 4×13.5 m with the implementation of these activities is increasing to 98.8 to 117 tph while reducing the specific consumption of electricity from 28.9 to 22.2 kWhpt. The parameter qpS reaches a value of $0.81 \cdot 10^{-4}$ kWhpm^2 in the production of cement CEM I 32.5 N. The metal content of products amounted to 5.65 tp(tph) at a specific volumetric productivity is 0.775 (tph)pm^3 [12].

Requirements to energy efficiency of the grinding process in a closed circuit ball mill cause the necessity of searching the optimal schemes of grinding. As shown by the charts grinding in the first chamber of the ball mill in the area of mill partitions can be up to 40...50 % of the finished size of the material that dampers the energy of grinding media, of course, reduces the efficiency of the grinding process coarse fraction. To solve this problem worldwide [13] is widely distributed TSG "BM–DS" with intermediate separation of the products of grinding, allowing to allocate of the total material flow the fine fraction. The product separation, as a rule, is directed to grind in the first and second chamber, where grind to a standard condition (Fig. 2).

A similar installation has [14] a three-chamber ball mill with size 4×12 m, cyclone separator with a diameter of 5 m, and the power plant is of 3.10 MW. With a capacity of 82 tph specific energy consumption amount to 41.5 kWhpt. The metal content of products amounted to 7.9 tp(tph) at a specific volumetric productivity equal to 0,63 (tph)pm^3. In the production of cement of type CEM I-42,5 R and S is equal to 3100 cm^{2}pg the parameter qpS is $1.34 \cdot 10^{-4}$ kWhpm^2.

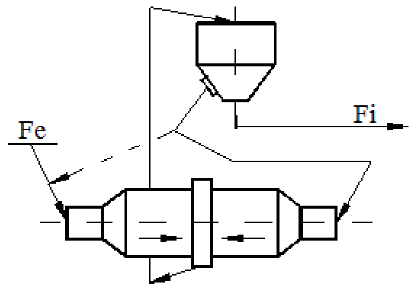

Fig. 2. Technological scheme grinding "BM–DS" with intermediate separation

When the external logic circuits discussed it has a number of weaknesses. First, located in the central part of the mill body window for unloading of grinding products significantly weaken the strength of the mill body, causing this crack, and secondly, the inability of the seal rubbing parts in the central part of the mill drum causes excessive dusting and spillage under the mill.

Also in this scheme the return material of the second camera is the almost finished product, which it is impractical to direct for further separation. To eliminate the last disadvantage developed TSG with intermediate separation with a direction of all coarse to the second chamber, the product on its dispersion is finish. Thus we can see an increase the parameter qpS to $1.16 \cdot 10^{-4}$ kWhpm^2. This may be explained primarily by the decline of the share over grinded material in the finished product. However, different mechanism of formation of the grain structure of products of both chambers of mills reduces the quality of the final product when it mixing.

The most promising of TSG with intermediate separation is a ball mill with two separators, two bucket elevators and a coarse direction parallel to the first and second chambers with independent circuits "camera–separator" for each camera [15]. This scheme is most economical in terms of specific energy consumption subject to offline configuration of each of the separators, depending on the dispersion of the incoming material. The disadvantage of the scheme is increasing the transport links, the complexity of system configuration and setup automatisation.

Limiting factor, limiting high efficiency ball grinding of clinker is the need to create optimal conditions for each stage of grinding in the drum mill. However, pre-grinding clinker to a particle size of 3...5 mm allows to exclude from the mill drum stage coarse grinding in a ball mill. Some progress got the TSG with pre-grinding cement clinker in a ball mill.

One of the most economical grinding plants of this type is used in Obourg (Belgium) (Fig. 3) [15].

Mill the first stage has a size of 6×3.5 m, power consumption 2020 kW and operates in a closed circuit with a vibrating screen with a mesh size of 2 mm. Mill of the second stage measuring 4.8×13.2 m working with two centrifugal separators with a diameter of 6.7 m for receiving the cyclones, the installed

capacity of the grinding unit 4410 kW. Product of grinding and classification the first stage enters to the separator of second stage.

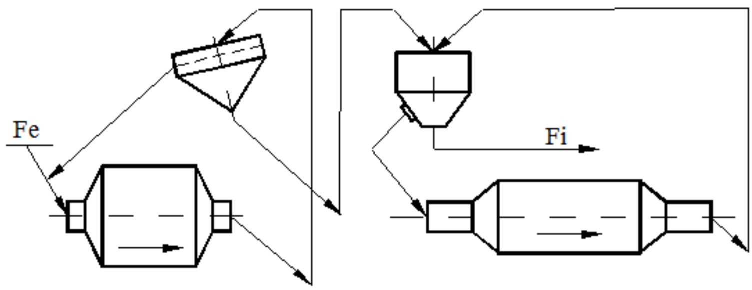

Fig. 3. Dual two-stage technological scheme of the drum mill and ball mills

Further, the product of separation (coarse) grinded till finish product in long ball mill. The plant capacity is 245...265 tph of cement with a specific surface area of 2700 cm^2pg (CEM I 32.5 N) and 155...170 tph cement with a specific surface of 3500 cm^2pg (CEM I 52,5 N). The total specific energy consumption in this case are, respectively, 27.7 and 44.3 kWhpt, including: by the mill the first stage is 7.7...11.9 kWhpt; the mill of the second stage is 16.4… 26.9 kWhpt; for the separation, transport and other auxiliary equipment 3.6…5.5 kWhpt. The parameter qpS respectively was up of $1.02 \cdot 10^{-4}$ and $1.27 \cdot 10^{-4}$ kWhpm^2. The metal content of products in the production of high quality cement was 5.6... 6.33 tp(tph) at a specific volumetric productivity of 0.5...to 0.56 (tph)pm^3.

Higher values of the parameter qpS and low values of specific volumetric productivity, compared with the TSG previously discussed types, with all the external logic of this scheme can be explained, first, low effectiveness of the separators. However, the concept forming the basis of this system is undoubtedly progressive for the following reasons:
– the grinding of clinker size of less than 2 mm increases the grinding efficiency in ball mill;
– in connection with increasing the amount of comminuted material passing through the drum of the ball mill, reduces the wear on the grinding bodies and lining per unit finished product;
– reduced power of ball mill of the second stage.

The drawback of this installation is the increase in items of main and auxiliary equipment requiring a large range of spare parts, therefore there is an increase in operating costs and capital investments.

Application of tube ball mill the first stage of pre-grinding (Fig. 4) allows you to get a fine product at the stage of rough grinding to evade from vibrating screen. Specific energy consumption for grinding of cement, corresponding to type CEM I 52,5 N, is 38.5 kWhpt, and the parameter q/S, respectively, of $1.05 \cdot 10^{-4}$ kWhpm^2, which is much better than a similar indicator of the previous scheme.

Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 point). Try to ensure that lines are no thinner than 0.25 point.

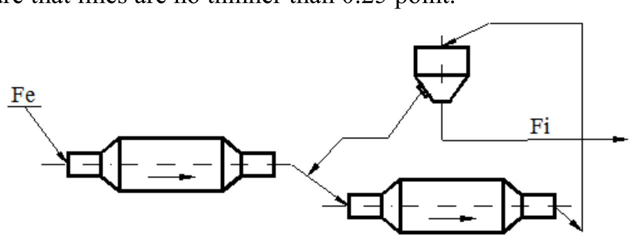

Fig. 4. Two-stage single-circuit of TSG with a tube ball mill under pre-grinding and "BM–DS" in the second stage

However, the intensive grinding effect of grinding media on the comminuted material causes increased wear of the lining tube ball mills of the first stage. Company Polysius created a ball mill "Doppelrotator", which is a drying and grinding installation with a drying chamber and two-way feed of raw material, coarse and hot gases. Material and gases are removed from it in the center across the output lattice. The difference between this mill, from the traditional is the fact that together with the flow of hot gases wet material through the trunnion of the mill hits in the beginning in the chamber of drying, where the lifting blades contribute to a more complete contact of the material with hot gases. From the chamber, drying the material through a slit partition with lifting blades gets into the camera coarse grinding, and then from the central discharge orifice is supplied to the separator. Large grains allocated in the separator, proceed in the chamber of a fine grinding, and some of them mixed with fresh material to improve its yield when entering the drying chamber. To passing a large amount of gas installed bearings with diameter up to 3.4 m under diameter of the drum of the mill 5.8 m Partitions the mills also designed to permit large quantities of gas. Currently operating mills "Doppelrotator" capacity up to 350 tph. With productivity of 270 tph of finished material and fineness of grind, the corresponding 12 % the residue on sieve 009, specific energy consumption accounting is 17.65 kWhpt for raw meal. The speed of gas flow in the coarse grinding chamber is 7.5 mps, and in the chamber of fine grinding – 2.5 mps. the Amount of off-gases from the mill is 400 000 m^3ph [16].

A modern approach to the improvement of TSG "BM–S" requires not only the installation of high-efficiency separators (S), but the separating of air flow and cleaning in separating systems for the dedusting of mill aspiration and technological separation of air. Moreover, increasing use is the scheme of deposition of the separated cement and clean separation of air in a powerful baghouse. Installation of a settling cyclone is not used, which allows to reduce the hydraulic resistance of the system and, accordingly, reduce the capacity of the separator fan.

Washing of crushing products by fresh air (in contrast to the circulating air in the system "separator–fan") allows to reduce the temperature of cement and coarse at 20...25 °C or more, first, improves the construction technological properties of the finished product, and secondly, allows to reduce the process temperature in ball mills.

Company FLSmidth (Denmark) for a similar reconstruction at the existing cement enterprises has developed a separator Sepax modification of IC [17-19]. On ball mill of size 4×12 m with the installation of a separate clean air flow when the finished product with a specific surface of 3400...3500 cm^2pg capacity was increased from 76 to 100 tph, and q decreased from 41.2 to 32.4 kWhpt. The parameter qpS decreased from 1.21 to $0.95 \cdot 10^{-4}$ kWhpm^2. The separator showed the separation efficiency at S = 3400...3500 cm^2pg about 80 %.

Company Christian Pfeiffer (Germany) in October 2007 in Mykolaiv (Ukraine) [20, 21] reconstructed a closed circuit ball mill size 4,0×13,5 m with with a dynamic separator QDK 29-N. Finished product with separator air is deposited in the bag filter performance 143 000 m^3ph. For aspiration of air is set baghouse performance 55 000 m^3ph. In the same source mentioned that the same project was launched in Russia in October 2007 in Voskresensk on the mill size 4,0×13,5 m with installation of separator QDK 29-N with individual bag filter. The firm mentions the reconstruction of TSG with a ball mill in a number of countries.

The most powerful performance filter installed in 2008 at the cement plant in Malagoj (Poland). Here the existing mill size is 4.4×14.0 m integrated with the newly constructed a closed circuit by means of dynamic separator *QDK* 29-*NZ*. All finished product is deposited in the bag filter, the performance of which is 220 000 m^3ph. The company believes that this is rational reconstruction and notes a decrease in the temperature of the finished cement and coarse to 75...80 °C. Due to the improvement of the separation process in dynamic separators, optimization of grinding process of cement clinker in a ball mill in the production of cement CEM I 42.5 N specific energy consumption amounted to 32...34 kWhpt and the parameter qpS (0.93…0.98) 10^{-4} $kWhpm^2$. The metal content of products is 5.85 to 6.15 tp(tph) at a specific volumetric productivity, component 0.69... 0.74 $(tph)pm^3$, which confirms the economic feasibility of such a reconstruction of modern grinding system with ball mill.

Conclusions

An analysis conducted by TSG "BM–S" with different schemes of their arrangement, showed that the production of ordinary cement types CEM I 42.5 CEM I 32.5 and specific energy consumptions range is 45 to 31 kWhpt, the metal content of products per unit of production ranged from 5.65 to 9.0 tp(tph) at a specific volumetric productivity of 0.6 to 0.775 $(tph)pm^3$.

The parameter qpS ranged from to 0.81 to $1.34 \cdot 10^{-4}$ $kWhpm^2$. This is the most promising of TSG on the basis of ball mills are of TSG, equipped with dynamic separators with the deposition of the finished product in the bag filter and the separator discharge of treated air into the atmosphere. However, opportunities to improve the energy efficiency of grinding process, reducing metal consumption and improving a number of other indicators, existing TSG of the type "BM–DS", are close to the limit, but they are still competitive with the most modern grinding systems.

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