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Modern grinding balls sorting machines

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INTRODUCTION

In grinding technologies employing ball mills, the most frequently applied working elements are steel grinding balls. The efficiency of the milling process depends on the grinding ball size distribution. During work, grinding balls wear away, thus reducing their mass; their diameter is reduced, and, sometimes, a loss of their spherical shape as well as cracks are observed. A loss of grinding balls' mass reduces the ball charge filling ratio (Duda, 1977). This loss is usually filled up with grinding balls having the largest diameter in a particular set of balls. However, this procedure leads to a change in the grinding ball size distribution, which results in deterioration of the milling process efficiency. The required parameters of the balls set can only be restored during the mill shutdown due to maintenance works and repairs. The mill is emptied of grinding balls and filled with a new properly prepared set. The balls from the unloaded mill chamber still have some use value and can be re-used to prepare a new set of balls provided that their diameter has not reached the pre-set limit value, there are no cracks and the shape has not been considerably deformed. Sets of balls are created of different dimensional classes of balls selected in adequate quantitative proportions (Duda, 1977). To be able to use the grinding balls from the emptied mill chamber, they must be first sorted into relevant dimensional classes. Sorting of grinding balls is a time-consuming process due to the number of balls, which can reach even 500 Mg (Zbroja, 2012). One of the methods of shortening the duration of the sorting process is to apply high-performance grinding balls sorting machines. Due to very little available information on these devices, the author decided to describe in this work the main types of modern grinding balls sorting machines, their construction and technological parameters as well as major problems involved in the process of sorting.

CRASSIFICATION OF MODERN GRINDING MEDIA SORTING MACHINES

There are many methods and simple machines for sorting grinding balls, but information about thm is scarce and hardly accessible. This study is focused on

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sorting machines for grinding balls which are currently used on a large scale, allowing for achieving good results. Modern sorting machines, apart from sorting balls into appropriate dimensional classes, provide the possibility to reject grinding balls with a diameter below the limit value and to eliminate grinding balls the shape of which has been considerably deformed. Moreover, they enable the grinding balls' surface to be initially cleared of impurities.
All sorting machines that have been described in this work in more detail have certain common constructional elements. They include a hopper of the feeder and a feeder of grinding balls, classification chutes and bulk containers. The element that makes particular constructions different from each other is the sorting subassembly. Based on the sorting subassembly, modern grinding balls sorters can be divided into classes: roller sorters, drum sorters, drum-roller sorters. The remaining solutions are used sporadically or have been removed from service. There are also solutions which until present have not been implemented, but allow achieving far higher efficiency. One of them is the solution presented by the author in other works (Piekaj, 2014) and (Sidor and Piekaj, 2015 and 2016). The proposed division of currently used sorters has been presented in Fig. 1.

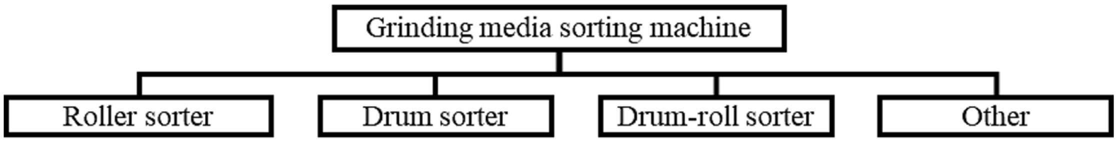

Fig. 1 Classification of grinding media sorting machine currently used in industry

ROLLER SORTER

The roller sorter belongs to one of the most common constructions that are currently applied in industry. A diagram of this device has been presented in Fig. 2., Fig. 3 presents an example roller sorter.

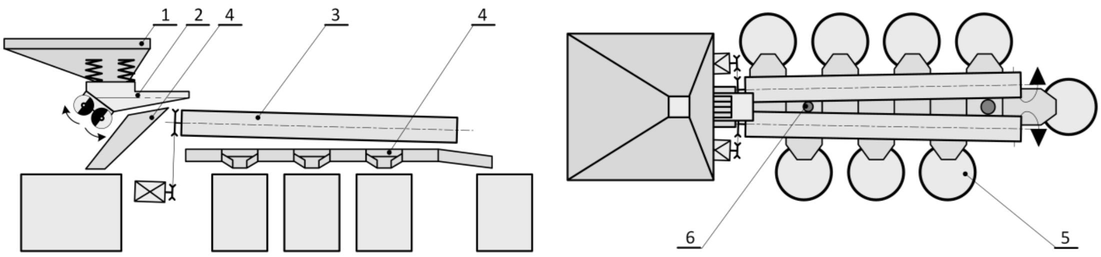

Fig. 2 Roller sorter diagram (side view – from the left, top view – from the right): 1 – hopper of the feeder, 2 – vibration feeder with grate, 3 – sorting roll, 4 – classification chute, 5 – bulk container, 6 – grinding ball

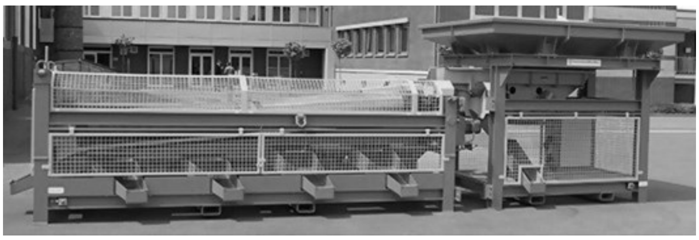

Fig. 3 A roller sorter without a support frame

Source: (Christian Pfeiffer, n.d.)

The sorter consists of a hopper for grinding balls with a vibration feeder, a sorting rolls assembly, a set of classification chutes and bulk containers. The working rolls assembly has been presented in Fig. 4.

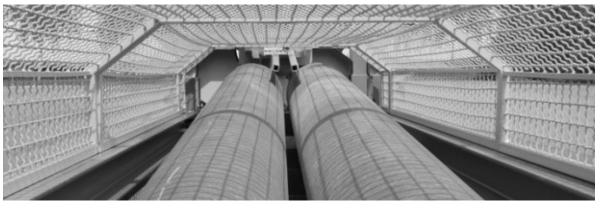

Fig. 4 A view of sorting rolls of roller sorter

Source: (Christian Pfeiffer, 2012)

The sorting process starts with filling the hopper, from which the grinding balls travel to the chute of the vibration feeder, most frequently characterized by linear motion. In newer constructions, the feeder chute is equipped with a special grate by means of which contamination in the form of dust, ground material remains, rust as well as small foreign bodies and grinding balls with dimensions considerably smaller than the limit ones are removed. From the feeder chute, grinding balls get onto the sorting rolls, which are responsible for the sorting process. The rolls' axes are divergent from each other so as to create a gap between them, the width of which at the beginning of the assembly is set to the assumed minimal limit dimension, whereas at its end, it is set to the width similar to the dimension of the largest grinding balls subjected to sorting. Additionally, the rolls assembly is inclined by an appropriate angle to the basal plane in order to improve the grinding balls' gravity movement. The concurrent rotational movement of the rolls prevents grinding balls from getting jammed in the gap and facilitates the movement of grinding balls with acceptable shape deformation along the cylinders. Owing to the divergent location of the rolls, at the beginning of the gap only grinding balls with the smallest diameter get through, whereas at its end – the ones with the largest diameter. The grinding balls getting through the gap in its particular segments find their way to appropriate classification chutes, by means of which they are delivered to bulk containers.

Some chutes are equipped with a flap closing the chute's outlet, which allows for changing the bulk container without stopping the sorter. An example of such a automatic flap has been presented in Fig. 5.

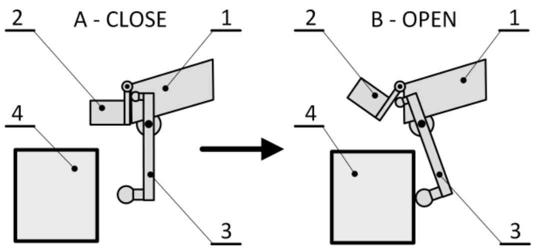

Fig. 5 A flap closing the chute's outlet diagram:
1 – classification chute, 2 – flap with weight, 3 – opening lever, 4 – bulk container

Only few constructions are additionally equipped with a subassembly responsible for improving the quality of sorting and rejecting the deformed grinding balls and foreign bodies. One of the examples is given in Fig. 6.

Fig. 6 A roller sorter with a belt conveyer
Source: (Cylian, 2015)

The advantage of roller sorters is simplicity of their construction and low investment expenditures as well as high efficiency of sorting in the case of grinding balls with larger diameters. Additionally, it should be emphasized that this kind of equipment can be used to sort cylpebs, though to a limited extent.
One of the major drawbacks of roller sorters is imprecise sorting, especially in the case of grinding balls with small diameters. It results from the uneven work of the vibration feeder, which by dosing an excessively large stream of grinding balls, causes their mutual moving. In this phenomenon grinding balls with larger diameters which did not get through the gap in the zone of their dosage, before leaving this zone are covered by grinding balls with a smaller diameter. As a result, when moving along the gap, the grinding balls with a smaller diameter rest on grinding balls with a larger diameter and are transferred to the classification chutes for grinding balls with a larger diameter. This phenomenon has been illustrated in Fig. 7.

Fig. 7 A view of the phenomenon of mutually moving grinding balls
Source: (Piekaj, 2012)

Roller sorters are or were offered among others by companies from such countries as: Brazil, Belgium, Germany, Canada, Turkey, China. A lot of unit models were also ordered by particular plants. Most of the constructions are adapted to sort grinding balls within a range of 15 mm to 100 mm, but there are also constructions with smaller ranges – examples have been presented in Fig. 8. There are considerable discrepancies in terms of sorting efficiencies declared by producers, and their values are usually quoted for the efficiency of sorting grinding balls with the largest diameter. In reality, this efficiency drops drastically as the diameter of the sorted grinding balls decreases.

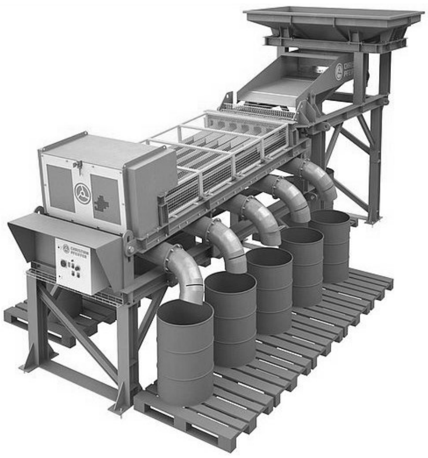

Fig. 8 A roller sorter with five sorting rolls
Source: (Christian Pfeiffer, 2016)

With regard to the manner of transport, roller sorters can be divided into sorters with their own wheeled undercarriage, adapted to be transported by e.g. a tractor (Fig. 6, 9) and sorters adapted to be transported by a truck equipped with forks, which are divided into two separate transport modules (Fig. 3, 8, 10).

Fig. 9 A roller sorter with a chassis
Source: (Asalmaz, 2012)

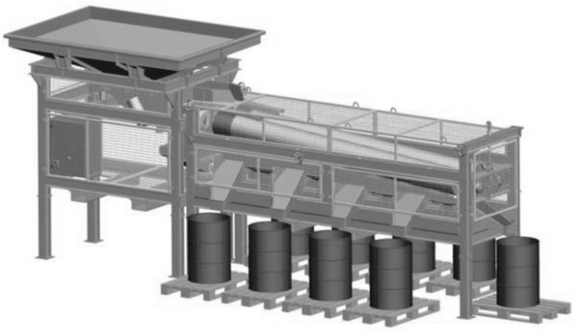

Fig. 10 A model of the roller sorter with a support frame and bulk container
Source: (Christian Pfeiffer n.d.)

The first module has a furnished hopper and vibration feeder and the other is equipped with a set of rolls, together with classification chutes. There are also stationary sorters.

DRUM SORTER

A drum sorter is another commonly applied construction. A diagram of this sorter has been presented in Fig. 11., Fig. 12. presents an example drum sorter.

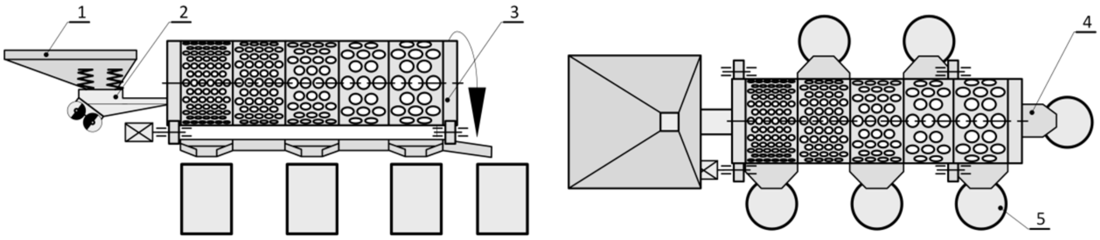

Fig. 11 Drum sorter diagram (side view – from the left, top view – from the right): 1 – hopper of the feeder, 2 – vibration feeder, 3 – sorting drum, 4 – classification chute, 5 – bulk container

Fig. 12 A drum sorter used in Cement plant in Namibia
Source: (Google Privacy: Magotteaux Ball Sorter Video n.d.)

A drum sorter consists of a hopper for grinding balls with a vibration feeder, openwork sorting drum, a set of sorting chutes and bulk containers. The sorting drum has been presented in Fig. 13.

Fig. 13 A view of interior of the drum sorter at work
Source: (Oliveira, 2013)

The sorting process, like in the case of the roller sorter, starts with filling the hopper, from which the grinding balls travel to the vibration feeder chute. A special grate for sifting impurities on the feeder's chute is applied only sporadically. Contaminations are removed by the sorting drum, to which the grinding balls from the feeder are supplied. The sorting drum is divided into sections, starting with a section having a sieve with a mesh size equivalent to the smallest diameter, and finishing with a section having a sieve with a mesh size of the largest diameter. Inside the drum there is a screw ribbon, which during the drum's rotation forces the movement of grinding balls remaining in the drum towards subsequent sections. The first section is usually responsible for removing dusts, the remains of ground material, rust as well as small foreign bodies and grinding balls the dimensions of which are much smaller than the limit value. Subsequent sections are responsible for sorting. Depending on the need, exchangeable drums for various dimensional classes and exchangeable sections are applied. Like in the case of roller sorters, the grinding balls that get through the mesh in the sieve of a given section travel to the classification chutes placed below, and next, to the bulk containers.

The major advantage of drum sorters compared to roller sorters is their higher efficiency when sorting grinding balls with small diameters, which results from the sieve section surface area. There is an opposite situation in the case of grinding balls with larger diameters.

Other drawbacks include the clogging of the drum sieve surface during work as grinding balls with dimensions slightly bigger than the size of sieve mesh get jammed. This may involve the necessity of stopping the sorter in order to clear the drum sieve area. The shapes of sieve surface mesh have been presented in Fig. 14.

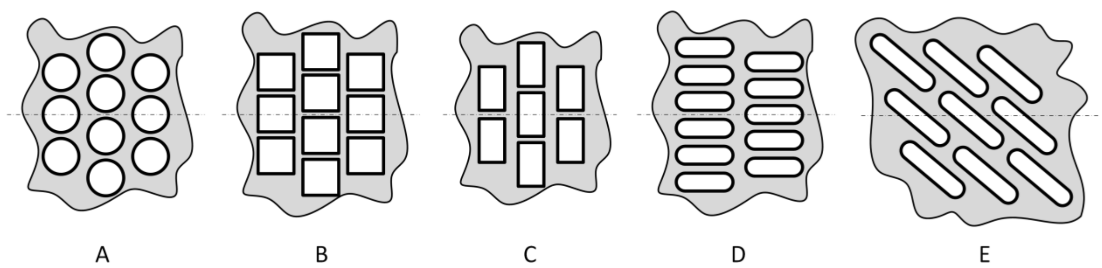

Fig. 14 Types of shapes of drum sieve mesh: A – circular, B – square, C – rectangle, D – rounded rectangle, E – rounded rectangle rotated by an angle

Like in the case of roller sorters, the values of sorting efficiency quoted by producers are estimated for grinding balls with the largest diameters – as the diameters of grinding balls subjected to sorting decrease, the efficiency drops drastically. However, it is better than in the in the case of roller sorters.

As far as transport issues are concerned, drum sorters, similarly to roller sorters, are available in a version with their own wheeled chassis (Fig. 13) or as two-module constructions to be transported by a truck equipped with forks. There are also stationary sorters.

DRUM-ROLLER SORTER

The drum-roller sorter is a combination of two sorters: a drum and a roller one. An example of this sorter has been presented in Fig. 15.

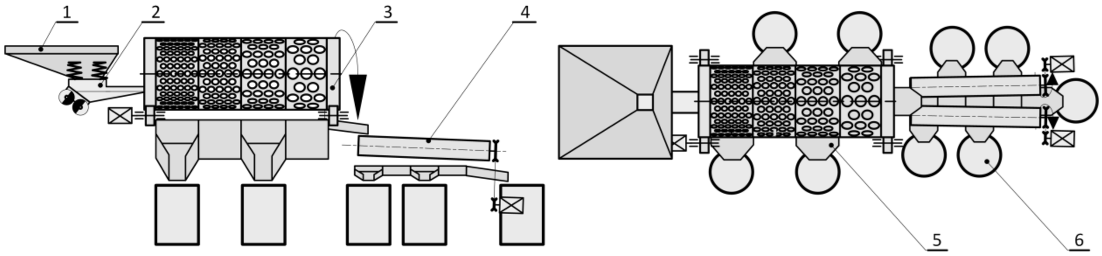

Fig. 15 Drum-Roller sorter diagram: 1 – hopper of the feeder, 2 – vibration feeder, 3 – sorting drum, 4 – sorting roll, 5 – classification chute, 6 – bulk container

The sorter consists of a hopper with a vibration feeder, a sorting drum, a set of rolls, classification chutes and bulk containers. An example of such a sorter's construction is given in Fig. 16.

At the beginning, the sorting process is exactly the same as in the case of the drum sorter – the grinding balls which before leaving the drum did not reach any of the classification chutes, get to the working rolls assembly, where the process of sorting is continued, as in the case of the roller sorter.

A combination of a drum sorter and a roller sorter in one device has resulted in a construction that has the advantages of both sorters, while eliminating some of their drawbacks. Grinding balls with small diameters are sorted in a sorting drum, which is characterized by a higher sorting efficiency than the roller sorter, whereas grinding balls with larger diameters get to the roller sorter, whose efficiency of sorting grinding balls with larger diameters is higher compared to drum sorters. The drawback of these constructions is higher capital expenditure and a more complex construction of the sorter.

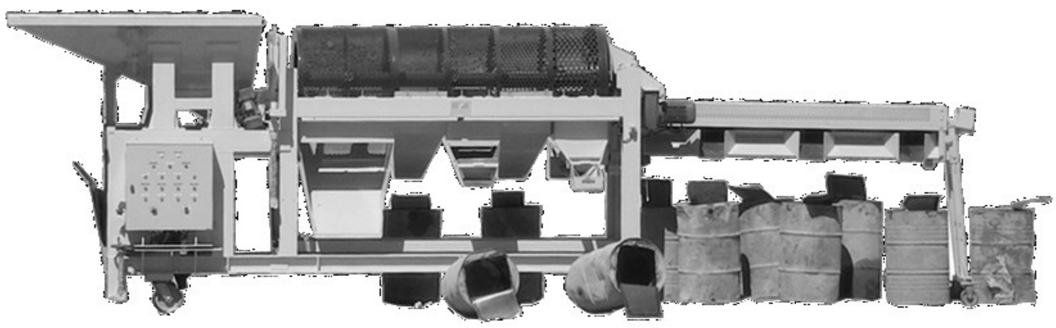

Fig. 16 Drum-roller sorter

Source: (Iteca Socadei 2014)

CONCLUSIONS

Taking into consideration the presented constructional solutions, one can define certain recommendations regarding the use of particular types of sorters. When sorting the grinding balls with larger diameters, it is better to use roller sorters, whereas in the case of grinding balls with smaller diameters, a more favourable option is the drum sorter. To efficiently sort grinding balls within the whole range of diameters, one can use both types of sorters – in such a case the best solution is to use the drum-roller sorter, which combines the advantages of both above mentioned sorters while eliminating some of their drawbacks. However,

currently used sorters still have a long sorting time, which indicates that it is reasonable to look for other construction solutions with greater efficiency.
Due to the lack of data on the efficiency of using sieves of various mesh shapes for drums. Research in this direction should be undertaken.
In connection with the continuous development of research on vibratory mills and the increase of their capacity of chambers. In the future, sorters can also be used in the industry using vibratory mills in which grinding balls are also used (Tomach, 2017).
Due to the small dynamic impact sorted object sorting roller after appropriate adjustment of their construction may be used in the classification of a product originating from the granulation process (Sidor and Feliks, 2015).

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Abstract.

Raw materials produced in large quantities are ground in ball, vibratory and stirred ball mills. In mills, the working parts are grinding balls. During grinding, grinding balls wear, change their diameter and lose their shape. The effect of this is the unfavourable change in the grinding balls parameters, which results in deterioration of the technological conditions of the milling process. Relevant parameters of the grinding balls set are restored during maintenance shutdowns. Grinding balls are sorted into appropriate size classes; grinding balls that are not suitable for further use are rejected, and then a set of grinding balls with appropriate parameters is used again. The time needed to prepare the required set depends mainly on the sorting time. To reduce this time, appropriate grinding balls sorting machines are used. The paper presents major problems associated with the grinding balls sorting process, a comparison of modern types of grinding balls sorting machines, a description of their construction and technological parameters.

Keywords: grinding media, grinding balls, sorting machine, sorting TAB, balls sorter