High efficiency separators in roller mills

Bernard H. Schonbach
Director, Product Development, Fuller Company, Bethlehem, Pennsylvania

Introduction
Roller mills have become the heart of the modern raw material processing plant. Efficient and economical operation is the chief reason for this acceptance. Four specific functions are performed within the framework of the roller mill:

- Grinding
- Drying
- Conveying
- Classifying

The grinding activity within the roller mill is far more controlled when compared to a ball mill system. Feed material is delivered to a rotating table which distributes the feed to each grinding roller. Specifically directing the feed to the grinding zone minimizes the random motions that occur in a ball mill. The upward conveying motion of the air stream creates a turbulent action which permits effective flash drying of resident moisture in the material. The conveying air also provides the source of air used for classification. With higher grinding efficiencies, lower specific power consumptions, and the coupling of mill airflow to many tasks, little attention has been paid to the classification system until recently.

The efficiency of the ball mill grinding circuit has been greatly enhanced with the advent of the O-Sepa cage-type separator. Unique design features allow the O-Sepa to provide exceptional performance by delivering high separator efficiency and broad system flexibility. Because the air and material forces are balanced throughout the classification zone, precise separation takes place which results in average capacity increases of 30% and reductions of 20 to 30% in specific power consumption when producing ordinary cement. Even though the flow patterns of the ball mill and roller mill are quite different, the same performance attributes of the O-Sepa separator can be designed into the roller mill. The cost for this modification is quite reasonable and the payback period is often less than two years.

Conventional classifiers
In conventional roller mills, the integral dynamic classifiers are not very efficient, although they perform better than static classifiers. The classifying mechanism consists of a spinning rotor with projecting vanes, positioned in the upper housing of the mill. A drop-out cone is sometimes employed to direct the coarse material fraction back to the grinding table for regrinding. The material stream is presented to the classifier in an upward spiralling path as shown in Figure 1.

A swirling motion is further induced in the material stream as it approaches the spinning

Figure 1. Roller mills with conventional classifiers.
The sweeping action of the rotor blades creates an outward centrifugal force and an obstacle in the path of the flowing stream of material particles as shown in Figure 2. Direct impingement of the blade on the material particles is responsible for imparting the tangential velocity of the blade to the particles and knocking them out of the flow stream. The centrifugal action on the material particles is counter to the inward flow of the material stream and is controlled by the speed of the rotor. Coarse particles which have lost sufficient velocity are not able to remain airborne and thus fall in the general direction of the outer wall or the drop-out cone.

Finer particles travel closer to the speed of the gas stream and can become re-entrained in the gas stream even if they are impinged by the rotor blades. The inefficiency of the classification process occurs when particles rejected by the rotor are directed back to the grinding table for regrinding but are instead re-entrained again by the gas stream. This action forms a recirculation in the mill body and the classifier housing without any useful work taking place. A schematic of this recirculation is shown in Figure 3.

Further inefficiency takes place when coarse particles block the path of finer particles and thus allows overgrinding of the finer particles. A natural agglomeration effect occurs when fine particles bond themselves to the larger particles, making classification more difficult.

Grinding energy is consumed in this process by the additional pressure differential of the gas stream required for this needless particle recirculation, and to unnecessarily grind particles finer than required.

**Circulating load**

Quantifying the internal recirculation of a roller mill is very difficult. In a ball mill circuit, the circulating load describes the number of cycles the material load passes through the ball mill for regrinding. Typical numbers range from 0 for open circuit mills, to 700% or greater for closed circuit mills. Circulating loads for roller mills have been stated to be anywhere from 500 to 2000%, depending on the system and the form of calculation. It is misleading, however, to compare these two numbers.

When a particle slides down the feed chute and travels under a grinding roller, it proceeds to be thrown off the edge of the spinning table. The high velocity of the upward moving gas from the louver ring entrains the particle and begins to accelerate it upwards. (See Figure 4.) The air energy contained in the moving stream is sufficient to initially propel most particle sizes.

If the particle is fine enough, it will become airborne in the air stream and spiral upward toward the classifier. If the particle is still rather large and heavy, it will fall out of the air stream and begin to drop to the table. The path back to the
Larger coarse particles eventually find their way back to the table for regrinding. Particles which are marginally oversize create problems. They may be caught up in swirling cycles or may be impacted by the upward flow and carried mistakenly through the separating zone and out the exit duct. Not only does this detract from the classifier performance, but the additional cycling and suspension of material in the upper classifier housing contributes to higher pressure drop requirements for the mill.

**Classification fundamentals**

In a milling circuit, the main classifying function is to remove the oversize fraction of a material stream and return it back to the mill for regrinding. Adjustments in the classifier setting provide for the control of the particle size distribution of the product. Good separating efficiency means reducing the circulating load of the circuit to minimize choking in the mill and to prevent over-grinding.

Many laws exist that describe particle movements in a gas stream. These are a function of many variables including particle shape, size, density, and velocity of particle and gas. Of particular interest is the ability to accelerate a particle in a swirling gas stream. The Stokes equation, listed below, relates the acceleration force of a spherical particle to the gas viscosity, particle diameter, and velocity difference between the particle and gas. Particle acceleration is shown to vary directly with the velocity difference and inversely with the particle diameter.

\[
gF = 3\mu DV
\]

where:
- \( g \) = dimensional constant
- \( F \) = drag force
- \( \mu \) = absolute viscosity
- \( D \) = particle diameter
- \( V \) = velocity

Coarser particles take longer time and further distance to accelerate to gas speed than finer ones. This natural effect allows a properly designed classifier the ability to provide good separation. An example of accelerating different size particles from rest is shown in Figure 5. Upon travelling a fixed distance,
some velocity range exists between the large and small particles. As the range becomes narrower, the selectivity between particle sizes becomes more difficult. This makes the job of the classifier more critical.

The way to graphically display imperfections in the operation of a classifier is to utilize Tromp diagrams. The Tromp curve involves calculating the selectivity efficiency based on knowing the particle size distribution of the classifier feed, the product fraction and the coarse reject fraction. The range of Tromp curves for separators with high and low efficiencies is shown in Figure 7. The slope of the curve indicates the sharpness of classification.

![Range of Tromp Curves for Separators](image)

**Figure 7.**

A steep slope indicates a good sharpness. The bottom part of the curve is the apparent bypass and illustrates the percentage of fines that remain in the coarse reject fraction.

Figure 8 illustrates the performance improvement in classification before and after the addition of an O-Sepa to a cement mill circuit. The differences in slope and apparent bypass show a vast improvement in separation efficiency and sharpness. For raw material processing, examples of Tromp curves for limestone separation studies performed in the O-Sepa pilot separator are shown in Figures 9 and 10.

![Incremental Recovery Graph](image)

**Figure 9.** Limestone study A: N°20 O-Sepa.

![Incremental Recovery Graph](image)

**Figure 10.** Limestone study B: N°20 O-Sepa.

**High efficiency classifiers**

The key to high efficiency classification is 'control'. There are many random motions that occur in the mill body that do not contribute to producing a uniform product. These motions are typically responsible for the high circulating loads that are often stated. The purpose of the classifier is to pass all particle sizes finer than a given setpoint and reject all larger particles back to the mill.

The O-Sepa cage-type classifier, Figure 11, consists of a set of stationary guide vanes which surround a spinning rotor. Material cascades downward into the classification zone where the inward force of the moving material stream is countered by the centrifugal force of the spinning rotor. The combination of uniformly spaced guide vanes and rotor blades along with a specific separating zone provide the environment for good separation to take place. The opposing forces in the separating zone create intense shearing forces which break apart agglomerated particle clusters.
As extraneous particle motions are reduced in a mill, less energy is wasted by needless recirculation. For a given operating condition, a roller mill with a high efficiency classifier will have a lower circulating load than the same roller mill with a conventional classifier system. Gaining better particle selectivity means that more material of product quality is removed from the mill with less circulation. This naturally results in less material being returned to the grinding table. Since the roller mill can be thought of as a volumetric machine, less material being returned to the table results in more space being made available for fresh feed, thereby increasing capacity.

Modernizing conventional roller mills

Simply placing a cage-type rotor assembly at the top of the roller mill does not insure the equivalent performance result as installing the same separator independently in a ball mill circuit. The principal difference in operation involves the way in which the separator is fed. Instead of gravity feeding material into the top of the distributing zone of the separator while air enters horizontally, both material and air spiral upward in the roller mill. This action complicates the classification process of the separator and contributes to a high circulating load.

Each mill geometry is characterized by a velocity profile. The highest velocity occurs across the louver ring and ranges typically between 70 and 90 m/sec for raw mills. Air leaves the louver ring at a shallow angle and helically coils upward into the mill. The large volume of the mill body allows the velocities to drop down to the 3 to 5 m/sec range before accelerating upward to the classifier assembly. The velocities approaching and passing through the separating zone are critical to classifier performance.

The cage-type classifier requires a defined velocity condition in order to work properly. Mounting this assembly into a roller mill involves studying the flow profile of the mill and designing a contoured classifier housing which can provide the correct airflow patterns with minimal pressure drop. In some cases, lowering the circulating load in the classifier will decrease the fan power requirement.

Uniform flow from the louver ring is an important precondition to good classification. Studies indicate that the air flows coming from the louver ring into the mill body are not uniform around the diameter.

Each grinding roller provides an obstruction to the flow path and results in specific and unique flow patterns. Improving the overall performance of a roller mill system first involves minimizing the pressure drop across the louver ring by properly distributing the gas. This is accomplished by utilizing some form of metal blocking or inserts to alter the different flow paths around the ring.

Figure 13 shows the adaptation of a high efficiency classifier in a large roller mill. These classifier modifications are also very suitable for smaller coal mills. Placement of the rotor and guide vane assembly in the mill is determined to give the best performance. The additional weight

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**Figure 11. O-Sepa separator.**

- Exit duct
- Product
- Dispersion plate
- Guide vanes
- Rotor
- Secondary air inlet
- Primary air inlet
- Tertiary air inlet
- Rejects

**Figure 12. Balance of forces in classifier.**

- Separation zone
- Fixed guide vanes
- Centrifugal forces
- Inward flow
- Horizontal partition plates
- Cage rotor assembly
- Coarse rejects
of the classifier components and drive require stiffening of structural members for support. Layouts involving the outlet ducting are required to arrive at a scheme which can be economically implemented.

Performance
Mill performance with any new modification must be judged comparatively against mill operation before any changes. Improved classification in a roller mill separator provides a cleaner separation cut and therefore allows for more capacity throughput. The block diagrams in Figure 14 illustrate this point. The material streams going in and out of the mill are easy to quantify but the circulation of material inside the mill outline is not available to view and requires other means to determine.

The left block summarizes the material flow streams for a roller mill with a conventional classifier. For this example a circulating load to the classifier is selected at 200% and the capacity of the mill is 150. The classifier feed rate will then be about 450 with 300 being returned to the mill as coarse rejects. The limiting point in the operation of this mill is the grinding capacity of the table.

The block on the right shows the same roller mill with a high efficiency classifier. Note that although the load to the classifier is about the same as the left block, more product quality material is able to leave the mill, leaving less material of a coarser fraction to be returned to the table. Because the circulating load is reduced, more room is made available on the grinding table for new feed.

A secondary effect of the improved operation occurs on the grinding table. The rejects cone under the classifier collects the coarse material and directs it toward the center of the grinding table. This stream of material is returned to the grinding table and creates a coarser matrix of packed material under the grinding rollers. From Figure 15 it can be seen that a coarser bed of
material in the grinding zone can actually increase grinding efficiency by removing much of the fine material which serves to cushion the grinding forces. Better control of the material bed on the grinding table can result in lower machine vibrations, depending on the material grindability and the grinding pressure required. Specific grinding power can be reduced by as much as 15% or more, depending on system conditions.

Product fineness is adjusted by varying the rotor speed. Increased rotor speed allows higher centrifugal forces to be developed in the blade area which rejects more material and results in finer product. The product distribution curve of a roller mill with a high efficiency classifier is steeper than that of a conventional roller mill. The three product distribution curves in Figure 16 represent test results from the Fuller laboratory roller mill with a conventional classifier and high efficiency classifier. The curves for the modified roller mill system show much better definition, specifically in the coarser range. Since mill airflow is controlled at mill exit conditions, the velocity requirements across the classifier are always maintained and the performance remains uniform over a wide range of operating conditions.

80% minus 200 mesh raw feed can be reduced to approximately 75% minus 200 mesh or more when using an O-Sepa, without any detrimental effect on burnability. In all cases the product from the O-Sepa separator was easier-burning at a fineness comparable to commercially prepared plant kiln feed.

Increased separation efficiency in a modified roller mill results in a narrowing of the range of particles in the mill exit stream. Less coarse particles carried over improves the burning process because the larger particles react more slowly in the kiln and are often high in unreactive silica.

Power savings are realized by reducing the fineness in the fraction passing 200 mesh to achieve an adjusted coarse fraction which will maintain equivalent burnability. Further, a fuel saving may also be realized by taking advantage of the easier-burning characteristics of the high-efficiency mill product.

Recirculation
The power required to operate the mill fan can be a substantial amount, often equal to or exceeding the mill drive requirement. Reduction of this power is a desired objective especially when the mill fan is the limiting component of the system. Reducing fan volume will lower the velocity through the louver ring and cause more material to be rejected through the louvers openings. Besides an increased rate of rejects coming from the mill, the kiln heat balance within the mill could be upset due to the drying requirements of the raw material. The threshold point for moisture content in a material with average grindability is approximately 8%.

Mechanical recirculation systems are available for roller mills to withdraw reject material from the mill and deliver it by bucket elevator to the top of the feed belt. Providing that the fan volume is able to be reduced without compromising the drying function, mechanically lifting the material to the top of the mill is more energy efficient than pneumatically conveying the same material.

Alternatively, this mechanical recirculation system could also be used to feed a high efficiency classifier mounted on top of the mill similar to feeding a separator in a cement mill circuit. Material would be directed to the feed points on top of the classifier and then onto the distributor plate of the rotor where the material would then be dispersed through the classification chamber. Providing material to the classifier in this way limits the amount of internal circulation that would occur inside the mill. The advantage in considering this option is the reduction of overall mill system power, and the possibility of some additional capacity increase.

Conclusion
The O-Sepa concept is now being applied to produce power savings and capacity increase in the raw material roller mill. Although roller mill efficiency is already greater than ball mill systems, further improvements can still provide a significant enhancement to mill operation and profitability. Installation of high efficiency classifiers in roller
mills has resulted in capacity increases of 15% and greater. At the same time specific power consumption has been reported to decrease by 10% or greater. Overall system improvement with the installation of a high efficiency classifier is a function of the current mill performance with a conventional classifier.

The key factor in improvement of classification performance is the specific design of the separation zone of the classifier and the control of particle motion. A properly designed high efficiency classifier will limit the amount of random motions that occur in the mill. This allows more fines of product quality to be removed from the mill which reduces the recirculated load and prevents inherent over-grinding. Decreasing the amount of internal recirculation in the mill decreases that static pressure requirement on the mill fan and actually improves the grinding efficiency on the mill table. Results have been verified by laboratory studies and actual commercial mill modifications. The cost for modifications are quite reasonable, offering payback periods of less than two years.

REFERENCES