1: Introduction

With an increasing focus on energy cost and demand for high machinery reliability and flexibility within the area of cement grinding, there has been a clear call to action to the equipment suppliers to deliver improved solutions into the market.

FLSmidth has proactively taken up this challenge through the years and has continuously developed the OK vertical roller mill to its current form (Figure 1) of being the most versatile and best performing cement mill in the market. The OK mill by FLSmidth has been proven for over 20 years and with 120 global references to be the premier solution for finish grinding of Portland cement, slag and blended cements.

2: General performance

With a power consumption of more than 30% of the total power consumption for a complete production line, the cement grinding installation is one of the biggest consumers of power. It therefore must be considered a potential and constant area for optimization.

With the combined capability of grinding, drying and separation the vertical mills are clearly seen as the preferred solution compared to other grinding processes.

The OK mill is the FLSmidth vertical roller mill offered for finish grinding. It is highly rated by our customers as an efficient, reliable and versatile finish grinder.

Efficiency: Low power consumption when compared to ball mill installations and to the other vertical roller mills on the market.

Reliability: The run factor is very high; more than 90% of the stoppages are related to the feeding or reject system and not directly related to the mill proper.

Versatility: Rapid change between feed compositions.

3: Mechanical

3.1: Grinding concept

The grinding portion in the OK Mill is significantly different from other cement grinding mills on the market.

As shown in Figure 2, it consists of a spherical shaped table and torus shaped rollers with a central groove.

- The inner part of the grooved roller evens out and consolidates the material before it continues to the next roller.
- The middle groove allows the air to escape from the grinding bed.
- The outer part creates highly concentrated grinding pressure.

The OK mill has the benefit of the material layer being very uniform, due to centrifugal forces and the inclined table leading up to the dam ring. Other roller mills of the flat bed type will accumulate material in front of the dam ring, making grinding more inefficient.

In Figure 3, two vertical mill types are compared running on the same plant and fed with the same clinker, clearly showing the significant energy efficiency benefit with the OK mill.
3.2: Grinding pressure

Even though the specific grinding pressure has been lowered to 1040 kN/m² the resultant peak grinding pressure is ~ 180 Mpa (Figure 4). This pressure is higher than any other vertical mill on the market. These high grinding pressures are the result of the quite narrow grinding zone on the outer diameter, which ensures the highest grinding efficiency.

3.3: Wear

A typical wear profile of the table and rollers in an OK mill are shown in Figure 5. Wear is concentrated to the narrow grinding zone on the outer diameter, thus minimizing maintenance requirements.

3.3.1: Eccentric roller support

To optimally utilize the wear segments, an eccentric bushing has been introduced which allows the shifting of the roller assembly position 60 mm (Figure 6), towards the center of the table, extending the running time of the segments before refurbishment. At the same time it is possible to optimize the precompression gap to the feed composition.

3.3.2: Wear parts

The wear parts are kept in Hi-Chrome material. This may be considered the "green approach" as it is re-weldable multiple times. Even recycling these segments is possible when the lifecycle of the wear segments ends. This is a more environmental friendly approach than using any type of ceramic composite materials which are difficult to reuse and are mostly considered as dead material that cannot easily be recycled.

3.4: Separator design

With the new ROKSH separator (Figure 7) the power consumption on the separation process is significantly lower if compared to our previous separators. The reduction of the absorbed power is approximately 25%. The profile of the mill housing and reject cone leads the dust loaded air flow to the louvre and rotor. This has been designed so that the air velocity is lowered through the separator. A resultant lower wear rate is found in the separator, actually so low that the separator housing does not require covering with hardfaced plates anymore.

The optimized separator has made it even easier to control the Particle Size Distribution (PSD).

3.5: Maintenance

When designing the OK mill great emphasis has been taken on making a maintenance-friendly and cost efficient design.

Rollers are designed with segments enabling the wear parts to be refurbished inside the mill by exchanging or hardfacing.

The rollers can also easily be taken out of the mill, enabling the mill to continue operation on two rollers on a four roller mill, and three or four rollers on a six roller mill. Typically, at least 60% of rated capacity can be maintained in this condition.

Split rotary feed sluices make for easy repair and refurbishment.

Figure 4: Specific/max grinding pressures obtained with different grinding profiles

Figure 5: typical OK mill wear profile grinding cements.

Figure 6: Eccentric bushing allows reposition and change of grinding profile

Figure 7: ROKSH separator for cement
In general, controlled airflow directs potential blasting away from main mechanical parts, thereby reducing internal maintenance needs.

4.1: Market development
Recent market developments have seen the average clinker production lines increase in size and the corresponding demands for cement grinding to grow. Traditionally to meet these requirements two or more mills would be utilized at a plant site. But now, there is often a preference towards fewer and more reliable machines which means that single cement mills are expected to support these larger, single kilns.

4.2: OK mill design
Already several years ago, FLSmidth expanded the original OK mill size range to cover up to 5500 kW installed power. With even higher demands, FLSmidth has now further extended the size range of the OK mill to include several 6-roller models with installed power of up to 12,000 kW (Figure 9). This enables a single OK mill to produce up to 685 t/h of cement product and satisfy the high capacity demand.

4.3: Gear/drive options
As a cement equipment manufacturer OEM, FLSmidth has for many years designed and produced quality gears for our vertical mills. All dependent on the size of the mill, there are different drive solutions available. Options include the traditional planetary drive (Figure 10), CEM drive and now multiple drive solution for the larger mills, enabling the customers to have only one supplier responsible for the complete grinding installation.

5: Process, operational and control considerations

5.1: Control of particle size distribution (PSD)
Normal vertical roller cement mills often show steeper inclination of the PSD curve than traditional ball mills. But if desired to meet certain requirements, the PSD can to some extent be controlled in multiple ways, with the ability to „flatten” the curve as, for example, shown in Figure 11. Other parameters such as dam ring height, grinding pressure, air flow and separator speed give further flexibility in optimizing sieve residue (Figure 12).

There is an increasing interest on the market for grinding to an even steeper PSD curve with a mix of more additives, including trass material as one of the latest.
5.2: Combined vs. separate grinding

There are two ways of handling additives - either by combined or separate grinding.

Within FLSmidth, we have good experience with both separate grinding and combined grinding, but there are still multiple issues to be taken into consideration. Figure 13 describes the main guidelines for an evaluation. It is recognized that separate grinding is generally more power demanding.

Previous grinding experience has shown that there is a tendency that even if the 28 days strengths are comparable, there can be some differences in the early strength developments measured. Figure 14 shows one example.

5.3: Dehydration of gypsum

Regardless of whether it is combined grinding or separate grinding which is used, it is important that the dehydration of gypsum is taken into consideration for processes that contain gypsum.

As the vertical roller mill is much more energy efficient than a ball mill, the amount of heat generated from the grinding is less, and the dehydration of the gypsum is lower. A good circulation of the process air is mandatory. This can be achieved by returning the ventilation air to the mill in order to keep the grinding heat in the mill circuit or providing additional heat to the air. If an external heat source is not available, increasing the feed clinker temperature may be considered. Furthermore, vertical mills have shorter material retention time than traditional ball mills, and this can be an issue how and when the dehydration occurs.

5.4: Pre-hydration

With respect to potential pre-hydration, the points of focus should be:

- **STORAGE** of clinker
- **GRINDING** of clinker with gypsum in cement mills
- **STORAGE** of cement/finish mix in silos or bags
- **TRANSPORTATION** of cement

The cement quality might be compromised in the grinding process, but also due to a combination of humidity, temperatures and carbonation during transportation or storage.

The chemical reactions that are normally found during the above mentioned scenarios are:

- Pre-hydration of clinker or cement: reaction with water or water vapour
- Carbonation: Reaction of clinker or cement with CO₂ (carbon dioxide)

When these reactions occur, they can normally be divided into 2 types of changes found in the finished product:

- Powder characteristics – often resulting in problems concerning handling of the cement
- Impaired flow ability, lump formation, blockages in silos, crust formation in bags
- Hydraulic properties, which may result in the cement not giving the optimum strength or resulting in problematic setting
- Reduced strength (especially early strength)
- Changes in setting properties

The gypsum dehydration in the mill and potential pre-hydration due to excess water injected into the mill and storage time/temperature must be balanced in order to avoid serious problems in the silos and with the final cement quality.

Today's market has shown that longer storage times are often necessary, and if the wrong assumptions have been made in relation to the operation of the mill, this may have a great effect on the finished product, the manufacturer's reputation for delivering a consistently high quality product, and certainly cost.

References:

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