OPERATIONAL EXPERIENCE FROM THE UNITED STATES' FIRST VERTICAL ROLLER MILL FOR CEMENT GRINDING

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ABSTRACT

For several decades the cement industry has successfully utilized Vertical Roller Mills (VRM) for grinding of raw materials and solid fuels. Most recently, this technology has been employed for the comminution of Portland cement, blended cements and slag cements. The VRM offers several benefits compared to the ball mill in regards to operating costs and flexibility. However, the quality of the cement produced is extremely important in cement grinding and there is little experience with cement produced from a VRM in the US market. This paper relates the operational experiences from the first VRM for clinker grinding put into operation in the United States in 2002. Included in the discussion are operational data, maintenance discussion and laboratory data focused on product quality. All of the discussion is based on comparison to ball mill operation at the same plant.

INTRODUCTION

Traditionally, the closed circuit ball mill with high efficiency separator has been the most common system for cement grinding. However, as happened with raw grinding over the last 25 years, the vertical roller mill (VRM) is now successfully being used for many clinker grinding applications and is rapidly becoming the standard for new grinding installations. The first such vertical roller mill installation in the United States was part of a total plant expansion and began operation in August of 2002.

Phoenix Cement Company modernized their existing three kiln plant to a state-of-the-art high efficiency operation by incorporating the newest technology available in the cement industry. Spurred by a growing demand for cement, the cement producer increased their clinker capacity from 1700 STPD (1590 MTPD) to a capacity of 3000 STPD (2700 MTPD).

For the new VRM cement grinding system, the cement producer contracted with an equipment supplier based in Bethlehem, Pennsylvania for a proven mill design that was originally developed in Japan during the early 1980's. ***FIGURE 1*** shows the VRM installed in the plant.

FIGURE 1: Vertical Cement Mill Near Phoenix, AZ

CEMENT GRINDING IN A VERTICAL ROLLER MILL

The differences between raw and cement grinding have been well documented in numerous publications and presentations over the recent past. Specifically, as compared to limestone, clinker and cement raw materials are finer and harder to grind. This, coupled with the finer and more stringent product particle size distribution requirements, entails design considerations to allow for continuous and stable operation of the grinding system.

The patented geometry of the mill's grinding parts has demonstrated its suitability for this application at the Arizona cement plant. As shown in ***FIGURE 2***, the rollers are spherical in shape with a groove in the middle. The table is also curved forming a wedge-shaped compression and grinding zone between the rollers and the table.

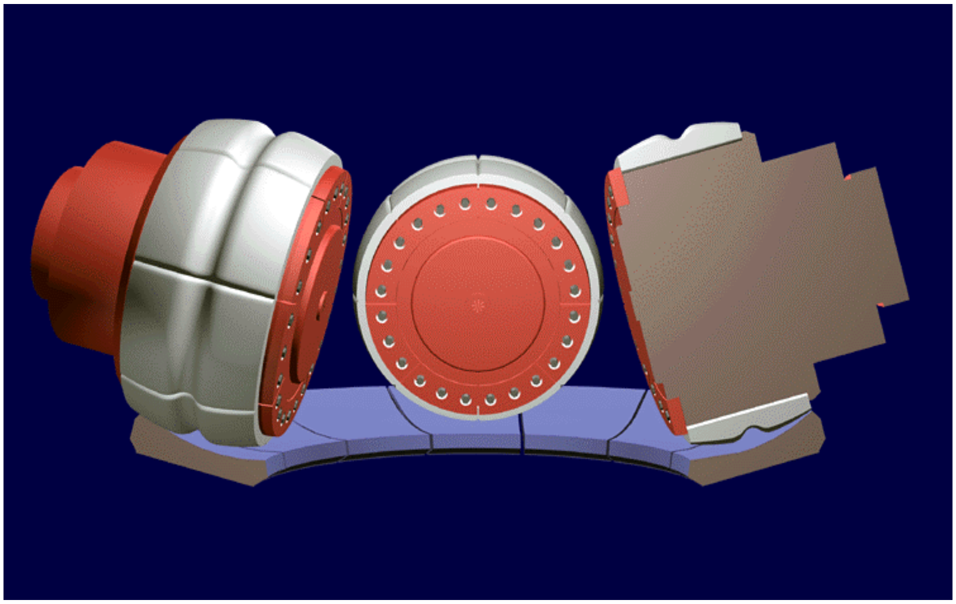

FIGURE 2: VRM Patented Mill Table and Roller Profile

The dual-lobed design is optimal for clinker grinding because it supplies two distinct grinding zones, a low pressure zone and a high pressure zone, at each roller.

The low pressure area under the inner lobe de-aerates and consolidates the material to be ground. This ensures a compact well established grinding bed for maximum stability. The proper grinding then takes place in the high pressure zone under the outer lobe. The groove in the middle of the roller facilitates de-aeration of the material without fluidizing it.

Due to its design of grinding parts and integral high efficiency separator, the vertical cement mill, as shown in ***FIGURE 3***, addresses all the difficult grinding conditions associated with the fine grinding of cement clinker and related products. The result is a high grinding efficiency and extremely stable mill operation.

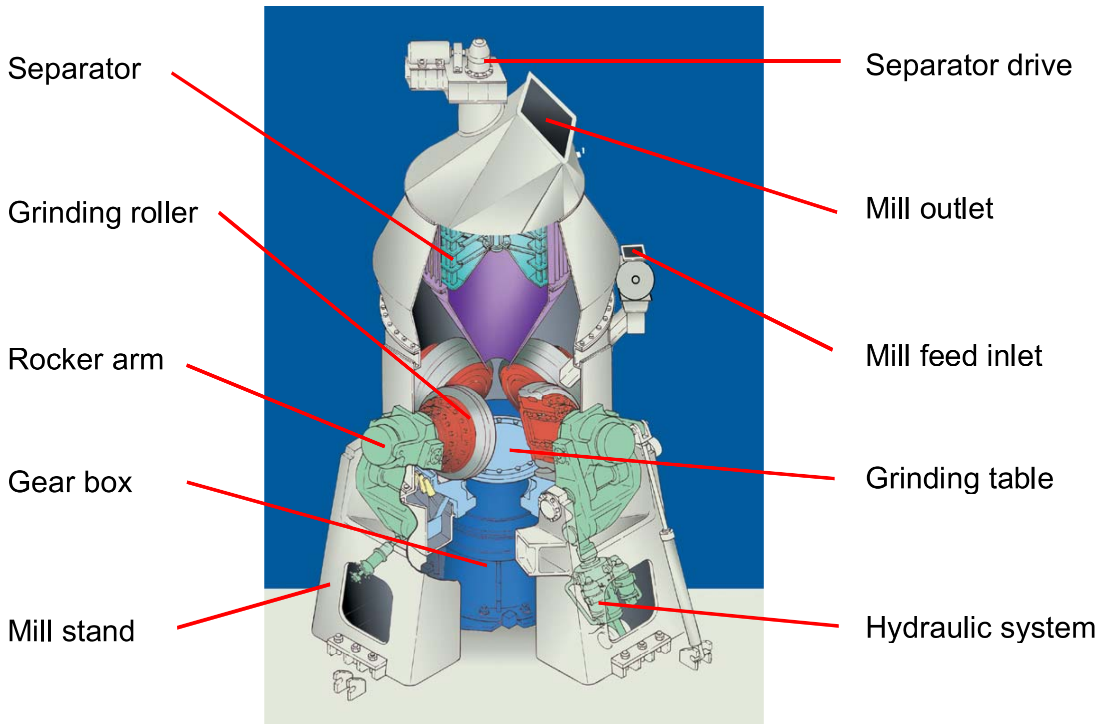

FIGURE 3: VRM for Cement

PROCESS

The cement producer, headquartered in Phoenix, is a regional supplier of Portland cements, gypsum, and fly ash products. Their vertical roller cement mill is one of the most modern components of the plant. Although the new mill was rated for 130 STPH (118 MTPH), it has operated consistently in the range of 140-150 STPH (127 to 136 MTPH) at a product fineness of 3900-4000 Blaine. ***FIGURE 4*** shows the cement mill production both immediately after commissioning and after 2 years of operation.

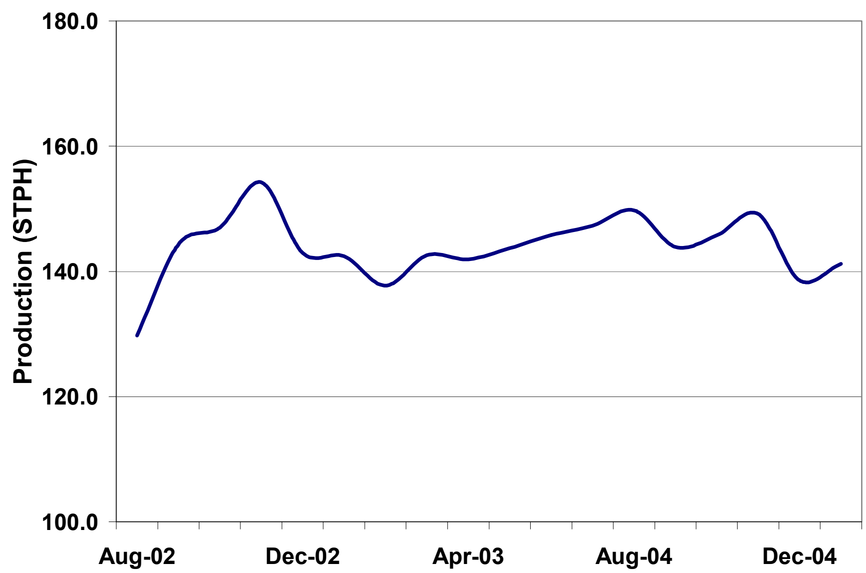

FIGURE 4: Cement VRM Production

Maximum capacity of 165 STPH (150 MTPH) was achieved shortly after commissioning. General operating conditions do not require this capacity on an ongoing basis; however the availability to meet a future increase in demand has been proven. In addition to increased capacity, a significant power savings was realized on the order of 16 kWh/MT of finish cement.

Ordinary Portland Cement: 95% clinker, 5% gypsum			
		VRM	**Ball Mills**
Production	**tph**	**144**	**31**
Mill Diff. Pressure	**mm WG**	**494**	**-**
Mill vibration	**mm/s**	**1.3**	**-**
Grinding aid	**%**	**0.018**	**0.018**
Blaine target	**cm^2/g**	**3900**	**3880**
Specific energy consumption:			
Mill	**kWh/t**	**18.3**	**35.2**
Classifier	**KWh/t**	**0.36**	**4.7**
Fan	**kWh/t**	**7.1**	**2.5**
Total	**kWh/t**	**25.7**	**42.4**

TABLE 1: Cement Mill Operating Data

As seen from the data in ***TABLE 1***, the VRM for cement grinding offers a significant advantage in power savings. Typically, the VRM uses 50% less power than a ball mill when grinding the same clinker to 3900 Blaine. VRMs are also much more adept at handling hot feed compared to ball mills.

The simple and compact vertical mill layout is cost competitive to build and offers many options for layout, even in existing plants. Today significant operating experience has been accumulated with vertical mills ranging from plant design and layout to operation with multiple types of product. One of the main focus points regarding cement VRM operation in the USA has been product quality and the product compatibility with existing ball mill systems.

QUALITY

In general the cement grinding system is required to consistently grind the prerequisite capacity of cement product while meeting all established product quality standards. The numerous quality parameters measured in a cement plant are assigned varying levels of importance depending on geographic region, individual plant operators and the needs of specific customers. Further, it is safe to say that consistency is equally important as obtaining any quality parameter.

The most commonly used measure of the mill system is product fineness. Based on established conditions under which the product yields the desired reactivity and consequently strength development, a standard particle size can be used to monitor mill consistency on an hourly basis. This usually takes the form of a single sieve residue or more often the specific surface (Blaine).

Because the effects of the mill on the quality of the product are more complex than what is practically reflected by a Blaine value or a sieve residue, the following product quality factors should be measured and monitored on a regular basis:

- The particle size distribution (PSD) and Blaine
- The degree of dehydration of the gypsum added to the cement
- The prehydration and carbonation of the clinker minerals

Various feed materials are known to behave differently from each other as a result of inherent differences in material characteristics. However, materials will also react differently according to the many types of grinding systems in which they are processed. A considerable data base of ball mill operation has been established throughout the history of ball mill cement grinding. The deficiencies as well as adequacies of ball mills are well known with regard to quality issues making the effect of each quality issue critical to understanding the VRM's reliability as a cement mill.

QUALITY CONTROL

In a cement vertical roller mill grinding is performed in closed circuit and with an integral high efficiency separator. This arrangement will give a good steep PSD. Experience has shown that the overall product particle size distribution is consistent with that obtained from a ball mill grinding plant with a modern high efficiency separator. During the initial VRM optimization period the mill is fine-tuned to match its product to the existing ball mills. This is achieved by making adjustments to operational parameters such as:

- Separator rotor speed
- Air flow rate
- Grinding pressure
- Dam ring height

Because the VRM has significantly higher grinding efficiency than a ball mill there is much less heat input from the grinding process. This is evident in the almost 50% less installed power, but is further taken into account with a smaller percentage of the energy being absorbed by the material. Compared to ball mills where 75% of installed power may be absorbed a good VRM will take only 50% of the installed motor power as heat. The end result is that the product will not be heated up as much as in a ball mill. This means that a lower degree of gypsum dehydration could occur.

A lesser degree of gypsum dehydration is not problematic considering two conditions; the inability to adequately control temperatures in ball mills creates an environment where operation is at the extreme of the gypsum dehydration. Additionally, less dehydration is not an issue if the gypsum is sufficiently reactive to control the setting reactions with a lower degree of dehydration as is normally the case.

If in special cases this is not the case different options are available to cope with the problem:

- Addition of more gypsum (within the SO_3 limit)
- Increased dehydration of gypsum by adding more heat to the mill system
- Addition of a more reactive form of gypsum

Prehydration is not typically problematic in a VRM as it is in ball mill systems where higher temperatures and internal water-cooling systems are common. However, if cement is produced at a relatively high temperature and still has a lot of gypsum that is not dehydrated one must be aware of the potential problem of gypsum dehydration coupled with clinker prehydration that can take place during storage in the cement silos. If a problem of this kind is present it can be coped with it by one (or more) of the following options:

- Ensuring that the cement is cooled to a lower temperature before going into the silo
- Provoking a higher gypsum dehydration level in the mill
- Replacing part of the gypsum with natural anhydrite

The actual VRM results achieved in Phoenix are built upon the theoretical rules for quality control presented here. During the initial period of operation, extensive quality data was recorded and analyzed. The results from comparisons between the existing ball mills at the Phoenix plant and the new VRM are presented in an abbreviated form. The data summarized below are based on

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significant results to comply with all plant requirements, but more importantly to conclusively satisfy all market requirements.

VRM AND BALL MILL PRODUCT COMPARISONS

To compare the similarities or differences between cement mill products of the same composition but produced in a vertical roller mill or ball mills, samples from each of the plant's mill types were taken and tested. All samples were obtained while the mills were producing the same product.

The existing mills are three circa 1950's ball mills from 2 different original suppliers. Two of the ball mills are 12 feet in diameter and 18 feet in length and each mill has twin 14 foot separators. These mills have 1500 horsepower motors and are rated at 30STPH. The third ball mill is a double compartment mill measuring 9 feet in diameter by 33 feet long with a single 16 foot dynamic separator. This mill also has a 1500 horsepower motor and is rated at 30STPH.

Particle Size Distribution

TABLE 2 presents a comparison of product particle size distribution from the 4 mills. Due to the inherent flexibility of the VRM and separator notice that the product fineness for the VRM does not match exactly, however key target residues are matched. More details of the balance between matching PSD and strength development follow.

	100um	45um	30um	10um	1um	0.6um	Blaine
Ball 1	1.0	96.6	73.7	39.0	2.5	0.78	3900-4000
Ball 2	1.0	96.7	74.4	39.2	2.9	0.65	3900-4000
Ball 3	1.2	94.0	70.1	38.5	2.8	2.3	3900-4000
VRM	0	95.8	68.8	40.7	4.7	2.2	3900-4000

TABLE 2: Product Particle Size Distribution Data

Strength Development

Strength development data for product samples from all 4 mills were compared. ***FIGURE 5*** shows comparative ASTM C109 cube strength results for the ball mills versus the vertical mill at two different Blaine targets. Notice the VRM has generally better strength development.

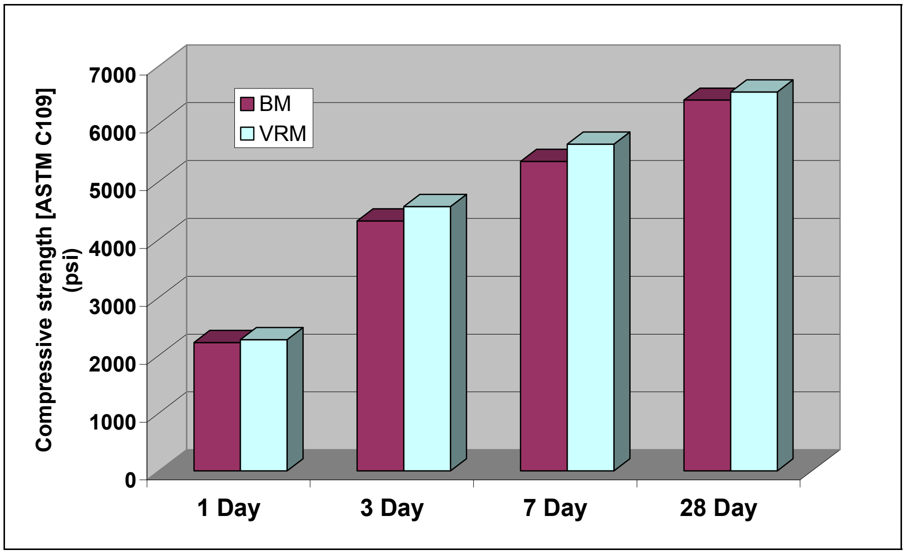

FIGURE 5: Compressive Strength Data

As mentioned above in the Quality Control section the gypsum dehydration and PSD will contribute to the cement strength development. By having the flexibility to adjust the operating parameters such as separator speed, temperature and dam ring height the PSD and dehydration can be controlled independently to achieve the necessary balance for strength development. The PSD from the vertical mill may not exactly match that of the ball mill; however the specific strength development will either match or show improvement. The improvement obtained in strength development was not possible with the ball mills due to inherent operational limitations.

Setting Times

For the two mill systems variations in setting times, shown in ***TABLE 3***, fluctuate as expected according to different Blaine targets. More importantly, faster initial and final set times are recorded in the VRM product than the ball mills for the same Blaine values. Significantly faster times are achieved when the Blaine target is raised. Because the VRM is more efficient these benefits are realized without the large penalties to power consumption seen in ball mills. The overall balance of PSD, strength development and power consumption make it possible to maintain low power usage while changing the Blaine or residue for improved product quality.

	Blaine	**Initial Set**	**Final Set**
Ball	3700	2:30	4:45
VRM	3700	2:00	4:30
Ball	3900	2:00	4:20
VRM	3900	1:30	3:45

TABLE 3: Comparative Setting Times

Dehydration

TABLE 4 compares dehydration products while grinding to a range of 3900-4000 Blaine. In the ball mills there is limited means to control the outlet temperatures. In the summer outlet temperatures reach 230-235°F and in the winter the range is 205-210°F. The table shows the effects of this range of seasonal temperature variation to dehydration products. With the ball mills it was common for the initial and final set times to vary by an hour or more during the year.

A significant advantage of the VRM is that the mill outlet temperature can be varied to control the balance of dehydration products. This in turn allows more consistent initial and final set times throughout the year. The last four rows of data in ***TABLE 4*** show the range of dehydration products achieved at various VRM Outlet Temperature set points.

	Outlet Temp (°F)	% Gypsum	% Plaster
Ball 1	215	2.3	0
	230	0.8	1.6
Ball 2	215	1.4	0.8
	230	1.6	1.1
Ball 3	225	1.6	0.3
	235	0.3	2.1
VRM	210	1.0	1.5
	220	1.1	1.7
	230	0.5	1.4
	240	0.2	0.4

TABLE 4: Cement Dehydration Products

Percent Water for Normal Consistency
The last issue for the VRM versus ball mills is the water demand.

The percentage of water added to cement to achieve normal consistency is a measured physical parameter. Water content is most affected by the PSD and gypsum dehydration. The water content in various VRM grinding plants has been seen to vary in a very small range according to the changes in these parameters. In order to control the water content the mechanical parameters that affect the PSD can be manipulated to find the correct balance of size distribution along with exit temperature to grind cement to the desired parameters.

Water demand is measured in three different ways. Normal consistency, flow with fixed water on Type I/II C109 cement cubes and water demand to secure a 4-5 inch slump on a standard concrete mix. By all three parameters the differences are virtually indistinguishable between the VRM and ball mills. For normal consistency the ball mill product requires 26.2 percent water by volume of cement. The VRM requires 26.0 percent.

General Quality
Several key quality parameters are presented above. Particle size and Blaine targets displayed were recorded at the settings determined during normal operation. In some cases changes were made to the product properties that were not possible with the existing ball mill grinding systems. In all cases there has not been any limitation encountered that could not be addressed through a practical adjustment.

MAINTENANCE OF WEAR PARTS

VRM technology was new to the Phoenix plant. During the initial operating period this proved to present many opportunities for new experiences and required a relatively steep learning curve that was not present with the ball mills. Despite the new skills to be learned and many new procedures to follow the process has been relatively smooth. Unexpected circumstances may present themselves at inopportune times; however the VRM has only had minimal down time.

The longest continuous period that the mill was stopped was 66 hours during roller maintenance. To date the reliability of the mill gives every indication that this will be the norm for the life of the system.

Through the first 2 years of full production the general trend indicates that maintenance costs are on the same level or slightly lower than for ball mills. It is expected that they will actually decrease as experience is gained and best practices are refined by the maintenance crew.

Wear

The VRM design allows the option of rotating the roller segments 180 degrees before replacing. They can also be hardfaced in place with a standard rewelding procedure. The table liners can also be replaced or hardfaced. As of this time both methods have been undertaken.

After the mill was in operation for over 10,000 hours the roller and table wear rates have been measured 2 times, once through each method described above, roller segment rotation and rewelding of both the table and roller liners. The actual wear rate for both the roller and table liners before hardfacing was 0.30 g/T. The measured wear rate with hardfaced liners was 0.12 g/T. The 50% reduction in wear rate with hardfaced liners was expected as data from other vertical cement mills indicated such a savings could be expected. In either case the wear rate has exceeded expectations and operation has not been detrimentally effected by wear.

CONCLUSION

Two years of cement vertical roller mill operation have proven the decision to invest in this new grinding application was the right one. The VRM continuously demonstrates the ability to make product equal to or better than existing ball mills with the tendency towards the better. The VRM product meets all market requirements in terms of both output and quality.

A higher level of operational flexibility and improved consistency has been maintained. Overall better efficiency allows for lower operating costs. And easy, predictable maintenance add further benefit to the bottom line. The Phoenix based cement producer is completely satisfied with the installation of a VRM for cement grinding.

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