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Fields of application covered by MVR grinding technology

Anwendungsbereiche der MVR-Mahltechnologie

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SUMMARY

The first MPS vertical roller mill for cement grinding was commissioned in 1980 and remains in operation 40 years later in 2021. MPS mills are well suited for many materials in different industries such as e.g. cement, gypsum, limestone, industrial minerals. Market demands for very high production capacities asked for bigger equipment. Due to the power limit in conventional gearboxes and limited size of MPS grinding tools, a new type of vertical roller mill, the MVR mill, was developed. With this concept a mill for very high throughput rates was made available. In combination with the special drive system, the so-called MultiDrive®, the system is equipped with double active redundancy both for rollers and the drive. Due to the modular concept of the MVR mill, small throughput rates are also well covered. The small MVR mills in compact grinding units, the so-called ready2grind plants, provide due to the modular, pre-fabricated plant a very short time to market and realization possibilities in remote areas or areas with challenging infrastructure. Topics such as sustainability, efficiency and digitalization are key drivers for development and are interlinked together. Continuous development of the MVR mill and the plant peripheral equipment is oriented to the needs of clients. This complies with key strategies to cut carbon emissions in cement production as well. Supplementary cementitious materials (SCM) to reduce the clinker proportion in cement are said to be the most effective measure of today for CO_2 reduction. With the flexible layout and versatility, the performance of MVR mills can be adjusted to meet not only product requirements but also energy efficiency and sustainability. Digital modules such as GPlink and GPpro offer functions to enhance the efficiency and performance. The MVR mill with its design and wide range of duty series, the flexibility when using SCM, the performance for cement grinding and the overall innovative approach provides a very flexible system that is reliable in support of decreasing the CO_2 footprint of plants.

ZUSAMMENFASSUNG

Die erste MPS-Wälzmühle für die Zementmahlung wurde 1980 in Betrieb genommen und läuft heute nach 40 Jahren in 2021. MPS-Mühlen sind hervorragend geeignet für die verschiedensten Anwendungen wie unter anderem in der Zement-, Kalk- und Gipsindustrie. Marktanforderungen in der Zementindustrie an größere Anlagen mit höheren Durchsätzen verlangen auch ein geeignetes Equipment. Konventionelle Planetenradgetriebe zum Antrieb des Mahltellers sind in ihrer Leistung gleichermaßen begrenzt wie die Größe der MPS-Mahltwerkzeuge. Das war die Erkenntnis zur Entwicklung einer neuen Wälzmühle mit der Typenbezeichnung MVR, mit der sehr hohe Durchsätze realisiert werden können. In Verbindung mit dem speziell dafür entwickelten Antriebssystem, dem so genannten MultiDrive®, ist die MVR-Mühle mit einer doppelt aktiven Redundanz ausgestattet. Dabei ermöglicht das modulare Konzept der MVR-Mühle auch kleine Durchsätze. Die kleinen MVR-Mühlen werden in kompakten, so genannten ready2grind Anlagen installiert. Diese Anlagen sind modular aufgebaut, vorinstalliert und ermöglichen damit einen schnellen Markteintritt und auch Installationen in entlegenen Gebieten mit herausfordernder Infrastruktur. Nachhaltigkeit, Effizienz und Digitalisierung sind heute die entscheidenden Herausforderungen für die weitere Entwicklung des Mahlsystems. Dabei ist die kontinuierliche Entwicklung der MVR-Mühle und des Anlagenequipments immer am Kundennutzen orientiert im Einklang mit den Schlüssel-Strategien zur Reduzierung der CO_2-Emissionen bei der Zementherstellung. Der Einsatz von Klinkerersatzstoffen wird heute als die effektivste Maßnahme zur Reduzierung von CO_2-Emissionen angesehen. Durch das flexible Layout und die Vielseitigkeit der MVR-Mühle im Hinblick auf Leistungsfähigkeit werden sowohl die Fertigprodukteigenschaften als auch die Energieeffizienz sowie Nachhaltigkeit gewährleistet. GPlink und GPpro als digitale Module erhöhen und verbessern die Effizienz und die Performance. Das Design der MVR-Mühle und der große Durchsatzbereich in Kombination mit der Flexibilität beim Einsatz von Klinkerersatzstoffen, die Performance bei der Zementmahlung und die kontinuierliche Entwicklung der Mühle bieten ein sehr flexibles System, das auch verlässlich zur Reduzierung der CO_2-Emissionen beiträgt.

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Anwendungsbereiche der MVR-Mahltechnologie

1 Introduction

With the introduction to the market of the MVR mill in 2010, a new concept was available for very high throughput rates. By using a larger diameter, a larger contact area resulting from roller size and/or number of rollers, a faster rotational speed and higher hydraulic grinding forces, the mill capacity can be increased. The MVR mill is also able to grind very small throughputs depending on the versatile module concept. The MPS mill, well known and proven for decades, was partially replaced by the MVR mill – especially for cement and raw material grinding as well for materials such as e.g. limestone, industrial minerals, slags and pozzolana.

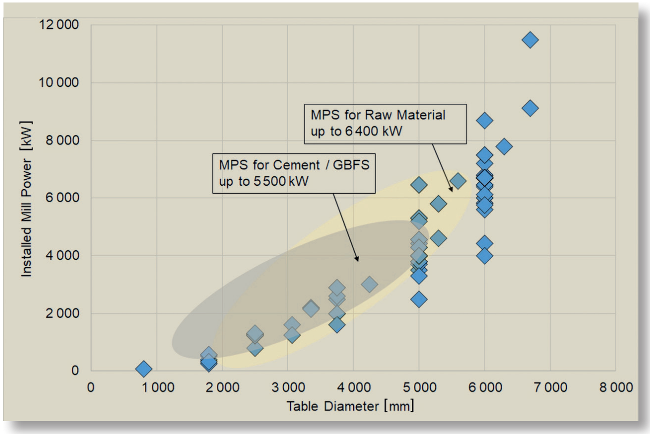

Figure 1: Table diameter and installed mill power for selected MPS and MVR mills

› Fig. 1 shows the duty series for MVR and MPS mills for cement and raw material grinding. Whereas the MPS mills for cement grinding and raw material grinding have been equipped with a power range between 500 up to 5 400 kW resp. 6 400 kW, the MVR mill covers a range with installed power between 60 up to 11 500 kW. Equipped with the so-called MultiDrive® there is a lot of available scope to go up to 18 000 kW.

2 Design features of MVR mill and MultiDrive®

The design features of the MVR vertical roller mill differ mainly from the well-known MPS mill in the grinding element geometry, in the roller suspension and the number of rollers. All machine parts that are relevant in terms of fluid dynamics, such as the hot gas channel, nozzle ring, the high-efficiency classifier and material feed, are of the same design as the parts that have proved successful in the well-established MPS mill.

The modular design of the MVR mill comprising four to six grinding rollers allows the continuation of mill operation even if one roller module is not available. The same applies to the so-called MultiDrive® design of the mill drive [1]: the mill is driven through a girth gear flanged to the grinding bowl by up to six actively redundant drive units with a total output of up to 18 000 kW. Each drive unit consists of an electric motor, a coupling and a gear. › Fig. 2 shows the decentralized arrangement of the drive. The grinding forces are transmitted to the foundation via a rugged table thrust bearing without placing any load on the gear units. Therefore, the gear units are not exposed to the grinding forces.

MVR mills are in operation with conventional planetary gear units up to 7500 kW. The principle of the MultiDrive® applies especially to mills with a bigger production rate and thus higher installed power. The smallest MultiDrive® is installed today at an MVR 6000 C-6 in Australia with a drive power of 5 500 kW (split in four drive units). The biggest one so far is installed at the mill MVR 6700 C-6 in Brazil with an installed drive power of 11 500 kW (split in six units).

The MultiDrive® has a lot of advantages. Due to the very low construction height the grinding plant layout is more compact and cost-efficient. When grinding different materials with highly varying grindabilities and target fineness, the system can be run with a frequency converter for speed variation. If this converter is not needed right from the beginning, it could be retrofitted anytime to adapt to changing requirements. The drive units are radially arranged on movable supports and can be withdrawn easily from the mill. With a maximum of 25 t per drive unit, the MultiDrive® has a much lower weight than a conventional gearbox and is easier for maintenance. Due to modular and lightweight design, using only standard components, stock-keeping becomes easier and less expensive. The MultiDrive® system extends the active redundancy to the main drive, because both drives

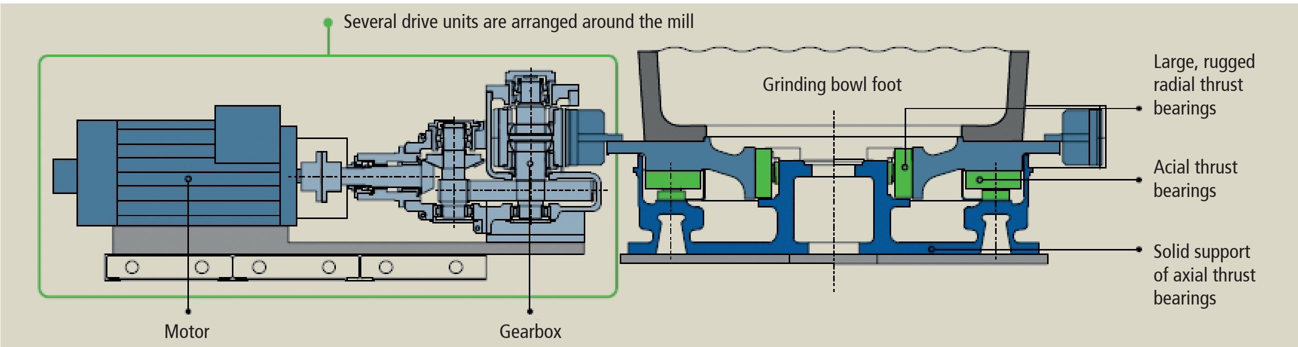

Figure 2: Schematic view of the MultiDrive® unit

Figure 3: View of the cement mill MVR 6700 C-6 in Brazil

and gear unit can be removed individually from the system and the mill can continue to grind. Together with the rollers, which can be taken out of operation individually, this is the highest level of reliability.

3 MVR mills for large capacities

The largest MVR mill for cement grinding is installed in the southeast of Brazil, close to the three most important cities in the country. The Barroso plant is equipped with two kiln lines and produces 3.6 million t/a of cement. With the installation in the year 2016 of an additional kiln capacity, a capacity of 2.6 million t/a cement was realized. The decision for the installation of an MVR mill was taken based on the lowest capital investment costs (CAPEX) for this grinding system. The grinding table of the MVR mill of the type MVR 6700 C-6 is driven by a MultiDrive® with six drive units, installed with a total power of 11 500 kW. The MultiDrive® is equipped with frequency converters so that the table speed can be adjusted to suit different finished product requirements. The MVR mill produces Portland slag cements with different granulated blast furnace slag (GBFS) proportions of up to 50 mass %.

The civil works were started in March 2013, mechanical and electrical installations began nine months later and are completed by September 2015. Hot commissioning took place in April 2016. ❱ Fig. 3 shows the completed mill with MultiDrive®. ❱ Table 1 lists the operating data of the production of different slag cements, achieved during the performance test. The flexibility of the equipment allows the production of a cement with a quality of CEM I with a fineness acc. to Blaine of up to 5 500 cm²/g, which was not defined in the project. The mill operates with a smooth level of vibration. During the commissioning and start-up no big issues were faced. The plant was running the mill without the supplier's supervisor after 79 h of commissioning. The flexibility of operation with less than six rollers or less than six drives is achieved due to the concept of active redundancy [1].

A mill of the type MVR 6700 C-6 installed in Algeria produces limestone-composite cement by inter- and separate-grinding of limestone and CEM I. The limestone is pre-ground in a raw material mill MVR 6000 R-6. Feed material to the MVR 6700 C-6 is clinker and gypsum. The preground limestone is injected into the classifier outlet and is homogenised with the CEM I in the filter and during transport to the product silos. ❱ Table 2 shows the performance results of inter- and separate-grinding.

Other MVR mills with MultiDrive® and thus double active redundancy are installed in Pakistan (MVR 6300 C-6), Cambodia (MVR 6000 C-6, MVR 5000 R-4), Australia (MVR 6000 C-6). ❱ Table 3 shows results for raw material grinding in a mill MVR 6000 R-6.

4 Compact ready2grind plants with MVR mill

After the crisis in the late 2 000 years, the clinker overcapacity was realized as severe. At the same time, several markets with comparably poor infrastructure were demanding small capacities in the range of approx. 20 t/h. The compact grinding unit, the so-called ready2grind plant [2] developed by Gebr. Pfeiffer, was the response to market demand. With the short time to market and the modular, pre-fabricated plant, project completion is very fast. These compact ready2grind plants are appropriate for remote areas or when cement production needs to be very close to cement consumers, even if the infrastructure is challenging. The pre-assembled construction of the modules with standard container dimensions makes precisely these factors possible in comparison to conventional grinding plants. Moreover, the majority of the steel construction for the grinding plant is integrated in the container structure. The electrical control system is also pre-assembled and wired and arrives at the construction site in an air-conditioned container.

Table 1: Operating data of a cement mill MVR 6700 C-6 installed in Brazil

Material mix	Unit	40 % GBFS, 3 % limestone	34 % GBFS, 9.5 % limestone	94 % clinker, 3 % limestone	94 % clinker, 3 % limestone
Product rate	t/h	410	456	178	238
Spec. power demand mill	kWh/t	26.2	23.4	38–41	32.3
Feed moisture	%	2.9	3.2	0.3	0.3
Fineness acc. to Blaine	cm²/g	4 600 5.2 % R38	4 420 4.5 % R45	5 500 0.9 % R38	5 025 1.2 % R38

Table 2: Limestone cement and Portland cement produced in a mill of the type MVR 6700 C- 6

Designation	Unit	Limestone Cement	OPC 2	OPC 1
Limestone injection (feeding point at duct to filter)	%	18	0	0
Feed to mill (only cli. and gypsum)	t/h	280	240	345
Total output	t/h	330	240	345
Fineness acc. to Blaine	cm²/g	4 700 4.0 % R45	4 800 3.0 % R32	3 875 2.5 % R45
Spec. power demand mill	kWh/t	17.6	24.5	18.7

Table 3: Operational results of a vertical roller mill MVR 6000 R-6 for raw material grinding

Designation	Unit	MVR 6000 R-6 Algeria		MVR 6000 R-6 India	
Installed main drive power	kW	6 120		7 500	
		guar.	achieved	guar.	achieved
Feed moisture	%	6.5	1.7	≤ 5.,0	4.9
Res. moisture	%	≤ 0.7	0.5		0.5
Product rate	t/h	680.0	692.0	550.0	735.0
Fineness R90	%	12.0	11.8	15.0	19.0
Spec. power demand mill	kWh/t	8.5	8.0	11.2	8.9

The savings resulting from the modular and standardized construction are up to 35 % as compared to conventionally built plants. The entire system can be adapted to suit the customer's needs in terms of material feed and product handling as well as the on-site layout, thanks to its modularity.

The use of the MVR mill as key equipment gives additional benefit. The investment costs which appear higher at first relativized within a very short time by the low operating costs of the MVR mill. In comparison to the MVR mill, systems with ball mills consume up to 40 % more energy. Because the MVR mill allows grinding, drying and classifying to be carried out in a single machine, there are also less auxiliary consumers. Maintenance and servicing costs have significant advantages in comparison to ball mills, which reduces the operating costs for the system even more. The short material retention time in the mill has a positive effect on the changeover of products and – in contrast to ball mill systems – no intermediate material, which would need to be discarded. Due to active redundancy, the MVR mill with its four grinding rollers stands for a high level of availability. This benefits the owner because it ensures that the mill remains operational during maintenance of the grinding rollers. Two opposed rollers can be swung out and the maintenance can be carried out while production continues at a capacity of at least 50 % [2].

A typical illustration is shown in ❱ Fig. 4. The installation sizes vary from 20 up to more than 90 t/h. The most common ready2grind plant type is the R2G 2500 C-4 with a production rate from 50 to 79 t/h of cement, depending on composition and product fineness (❱ Table 4). ❱ Fig. 5 shows pictures of ready2grind plants with the mill type MVR 2500 C-4.

5 Supplementary cementitious materials

Supplementary cementitious materials (SCM) or clinker replacement materials (CRM) influence the grindability and operational behaviour and reactivity. These materials have been in use for many decades. The amount of composite cements is still increasing considerably. SCM can be artificial or natural. Artificial SCM are for example fly ash, granulated blast furnace slag (GBFS), silica fume. Natural materials are e.g. limestone, pozzolana, clay. In many countries, limestone is the most easily available supplemental material. Limestone dilutes the clinker content of the cement and impacts the strength development. If natural pozzolana is available, the hydraulic properties are advantageous for cement products. The definition of pozzolana includes any volcanic material. In difference to that, the term "pozzolan" does not describe the specific origin of the material [3]. Therefore, the term "pozzolan" also includes artificial supplementary materials, such as fly ash, bottom ash etc. The great majority of natural pozzolans is of volcanic origin. The global distribution of volcanic rocks can be compared

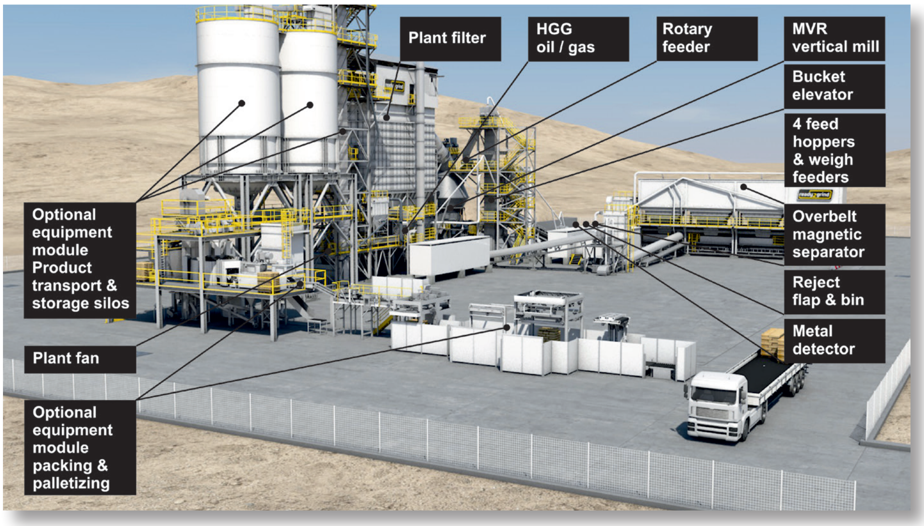

Figure 4: Illustration of a typical ready2grind plant

Figure 5: ready2grind plants equipped with the mill type MVR 2500 C-4

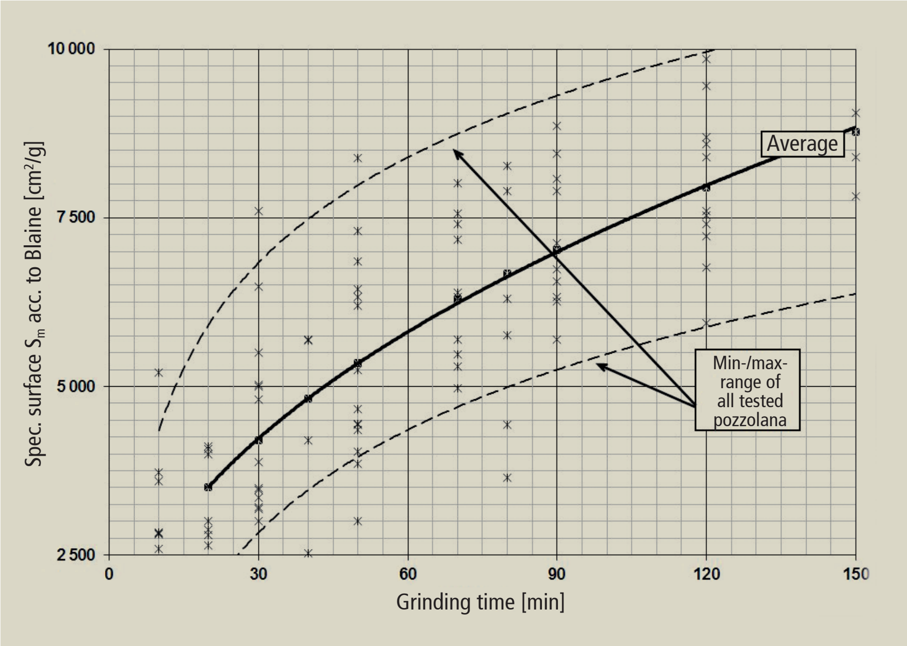

Figure 6: Pozzolana grinding in the lab ball mill – the Blaine value as function of grinding time [6]

with the occurrences of natural pozzolan deposits. But not all volcanic rocks are suitable as pozzolanic material. More siliceous magma produces more explosive volcanism with better pozzolanic properties [4]. The activity of some pozzolanas, for example phonolith, can be increased by thermal treatment. By heating up to 300 to 500 °C, the crystal lattice expands and the surface area increases. Thereby the formation of hydrate-phases is supported [5]. The grindability of natural pozzolana varies widely. In ❱ Fig. 6, the specific surface area acc. to Blaine depending on the grinding time is shown. For achieving 5000 cm²/g acc. to Blaine, for example, a time of exposure in the laboratory ball mill is between 30 to 80 min (average 45 min). This behaviour has to be taken into consideration for rating the industrial mill. Additionally, the reactivity of pozzolanas is very different and has tremendous impact, in combination with the clinker, on the produced cement. Therefore, a fine adjustment of feed material properties and target fineness of finish product needs to be done.

When it comes to composite cements, the versatility of MVR mills is impressive. These mills are very flexible when it comes to grinding different materials, such as: clinker, limestone, GBFS, pozzolana, fly ash, bottom ash, etc., with a wide range of properties. When moist materials are included in the feed mix, a heated rotary lock will be installed, when dry and already quite fine materials are relevant, an additional feeding point is provided at the classifier housing.

When producing composite cements the decision between inter- or separate-grinding is often under discussion. The MVR mill is able to switch from inter-grinding to separate grinding depending on the client's needs without any changes to the mill internals. Properties of, for example, GBFS and fly ash vary widely. In line with the required product properties it has to be taken into consideration that inter-grinding can result in finer fractions containing either very little or no GBFS or fly ash. Depending on the reactivity of GBFS, the mode of production can be achieved with inter-grinding as well with separate grinding of the single components. Operational experiences show that plants tend to grind clinker and GBFS together if GBFS is available with a good reactivity. One advantage of inter-grinding is the formation of a stable grinding bed due to clinker and GBFS granulometries which interact positively. If the GBFS needs to be ground to a high fineness due to lower reactivity then separate grinding might be a better way to achieve the overall required properties of slag cements. MVR mills are operated in both ways (s. Table 2).

As cement is the most widely consumed building product in the world, a huge volume is produced. Therefore, cement production is responsible for about 8 % of man-made CO_2-emissions [7].The International Energy Agency (IEA) has highlighted four principle CO_2 reduction levers. Key strategies to cut carbon emissions in cement production include improving energy efficiency, switching to lower-carbon fuels, promoting material efficiency (to reduce the clinker-to-cement ratio and total demand) and advancing process and technology innovations such as CCS [8]. Reducing the clinker proportion in cement is said to be the far most effective measure. Consideration of SCM replacing clinker in cement is only part of the picture but gives a good indication to evaluate the effectiveness of composite cements regarding the CO_2 footprint.

A comparison for energy use and CO_2 emissions for CEM I (91 % clinker) and CEM II/B-V (Portland fly ash cement with 68 % clinker) evaluates the energy use to about 4000 MJ/ton of CEM I and about 3000 MJ/t of CEM II/B-V [9]. These figures contain input of clinker production, electricity consumed by cement mill section, packing plant section and auxiliaries. The CO_2 emissions result in 800 kg CO_2/t of CEM I and 600 kg CO_2/t of CEM II/B-V. The energy use and CO_2 emissions of the composite cement are at least 20 % less compared to Portland cement. For evaluation of energy use and CO_2 emissions the proportion of SCM has to be considered, but also the product fineness of the composite cement impacted by reactivity of the SCM in use. As not all supplementary cementitious materials give a sufficient reactivity at a lower Blaine value the product fineness overall has to be increased under certain conditions.

Table 4: Production rates of MVR 2500 C-4 mills

Type	Unit	CEM IV/A Plant A	CEM I Plant B	CEM II/B-P Plant C	CEM II/A-L Plant D
Capacity	t/h	61	70	67	32 to 36
Fineness acc. to Blaine	cm²/g	4500	3500	4000	4900 to 5600
Spec. energy demand mill	kWh/t	15.9	17.2	17.5	23.1 to 24.6

6 Performance

The performance of a vertical roller mill is defined by a required throughput at a required product fineness paired with a low specific thermal and electric energy consumption. For cement grinding, the required product quality is the most important target together with the above-mentioned points. Some areas in general need special attention: feed uniformity, metal detection and extraction, and preventive maintenance to name just a few. The levers to pull for a well performing vertical roller mill are operational parameters such as table speed, gas flow, working pressure and mechanical adjustments such as dam ring height and covering the nozzle ring. A smooth and stable mill operation with reduced or zero water spray is possible, hence grinding without external heat depends on the moisture and temperature of the feed material. The product fineness also impacts the level of grinding without external heat, i.e. the higher the product fineness, the higher the heat produced by grinding. That means, for a cement with a high Blaine value a higher feed moisture is acceptable without addition of external heat compared to a cement with a low Blaine value. The clinker temperature is a factor to be considered as well. For both grinding plants listed in ❱ Table 5 the mill was heated up with the fan to a classifier outlet temperature of approximately 65 °C.

Table 5: Examples for cement grinding without external heat

Designation	Unit	Plant E CEM I	Plant F CEM I with 4 % limestone
Feed moisture and water injection	%	1.3 to 1.4	~ 1.1
Clinker temperature	°C	ambient	50
Fineness acc. to Blaine	cm²/g	5 200	3 850
Production rate	t/h	85 to 90	215 to 225
Spec. power consumption mill	kWh/t	29 to 35	18 to 22
Temperature at classifier outlet	°C	75 to 80	~ 80

The success of the vertical roller mill in cement grinding was achieved by producing the same or better cement quality. This cannot only be traced back by adjusting to the same or similar particle size distribution, but also to the adjustment of feed material properties (clinker C_3A) and especially sulfate agent proportioning. The sulfate agent needs a balanced proportion of di-hydrate, hemi-hydrate and anhydrite. As a VRM has a significantly higher energy efficiency than a ball mill, much less heat is put into the grinding process. As a result, the dehydration degree of the sulfate agent is lower. The lower hemi-hydrate or plaster content can be compensated for by the addition of more gypsum (within the limit according to the relevant standards), by the addition of a more reactive form of gypsum, or by the addition of more heat to the system. By installing the G4C® system with a separate hammer mill and hot gas generator to partially calcine the gypsum, the hemi-hydrate content can be controlled exactly for each clinker that is used. This is made possible by setting the outlet temperature of the hammer mill to adjust the proportion of hemi-hydrate. This system is installed with a mill of the type MVR 6000 C-6 in Australia and supports a tailor-made sulfate agent for the finish product.

The performance of a VRM can also be impacted by grinding aids. Grinding aids are very common today – resulting in production increase, early strength enhancement, improvement of workability etc. MVR mills can be operated without grinding aids, but performance is supported by the use of grinding aids. The general application of grinding aids depends strongly on the manufacturing company and the region where the plant is located. Other factors include the cement type and product fineness.

❱ Fig. 7 shows the fineness for cementitious products ground in MVR mills [10]. The types are divided into OPC, GBFS (blast furnace slag), PLC (limestone cement), PSC (slag cement), PPC (fly ash cement), PPC-P (composite cement with pozzolan). Cements with more than one supplemental cementitious material are classified according to the SCM with the highest proportion. Only OPC and PPC cements are ground to a fineness of less than 3 500 cm²/g acc. to Blaine, the major proportion of cements is ground in the range between 3 500 and 4 500 cm²/g, more than one-third of the products of high fineness (> 4 500 Blaine) are ground to 5 000 cm²/g and higher. This reflects both the necessity of higher fineness for supplemental cementitious materials in order to achieve sufficient reactivity in the later application, and also the fact that an OPC cement can be easily ground to a fineness acc. to Blaine of more than 5 000 cm²/g in MVR mills. ❱ Fig. 8 shows the use of grinding aids for different types of cement produced in MVR mills. In this evaluation all operating MVR mills for cement and all the different products ground are included (this is also true for the data in Fig. 7). Cements with a fineness acc. to Blaine of less than 3 500 cm²/g are generally ground without grinding aids, for a fineness ranging between 3 500 and 4 500 cm²/g one-third is ground with grinding aids, for high fineness ce-

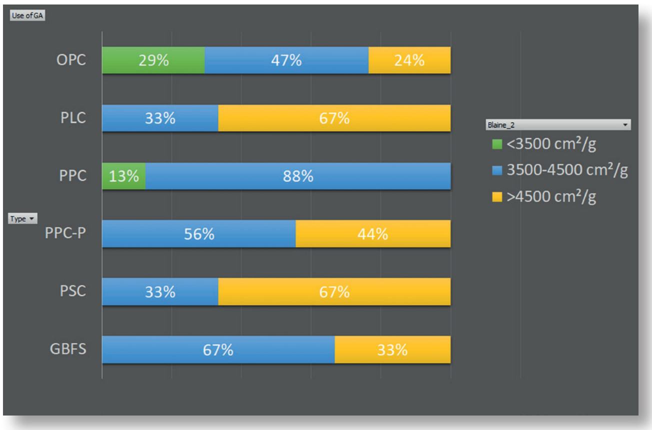

Figure 7: Fineness of different cement types ground in the MVR mill

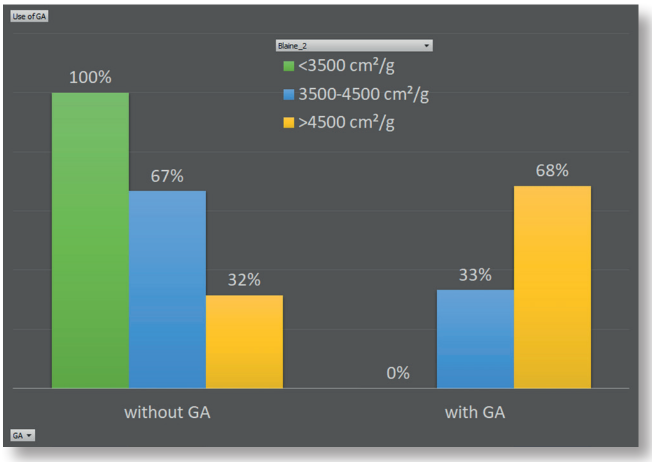

Figure 8: Use of grinding aids at different product fineness

ments more than two-thirds are ground with the application of grinding aids.

An important factor in the characterization of cement properties is the strength development in combination with setting times. National standards define the procedure for testing. Due to differences in those standards, the results of compressive strength development are not comparable to each other. Gebr. Pfeiffer has its own mortar laboratory and collects samples from operating MPS and MVR mills to characterise cement product properties. To ensure the reliability of results, the laboratory participates in annual round robin tests (ATIHL3 and BE CERT4). The procedure for sample preparation, proportions for cement, sand and water are in accordance to EN 196-1. The properties of several cements produced in MPS and MVR mills are listed in ❱ Table 6. Nearly all OPC/CEM I products have developed a 28 d strength of 60 MPa or higher. High 28 d strength figures are achieved as well with a product fineness less than 4000 cm^2/g acc. to Blaine. Early strength after two days is clearly impacted by clinker quality and, for composite cements, the type of composite is an additional factor. The composite cements achieve high 28 d strengths. Products need to be ground fine enough due to composites in order to get the required strength level. The given normal consistency figures have been determined in accordance with EN 196-3 and demonstrate that workability of products from MVR mills meets the demands of industry. Custom specific adjustments have been made in many cases during commissioning of MVR mills, for example: PSD adaptation, sulfate agent selection, or the use of the G® system to get precise plaster-content. These results show that cements ground in vertical roller mills are clearly on the same level compared to cements ground in ball mills.

7 Digitalization

Industry 4.0 is also a driver for clients to cover operational support. This feature is offered as digital "modules" where Gebr. Pfeiffer focuses on maintenance and enhancement of operation at the moment. One of these digital modules is GPlink which stores sensor data for data analysis and enables 24/7 access to data from mobile devices. When transmitted to the company's service team a solid basis for support and rapid and targeted assistance is given. GPpro facilitates the Advanced Maintenance System with scheduled maintenance and is adapted for actual needs. This system includes a wider range of sensors as well as a data analysis tool and reports partly with the help of artificial intelligence. Reacting to the changing requirements this product is developed further. The modular structure offers functions in the areas of e.g. preventive maintenance, protection of the mill, reduction of water consumption. The module "dynamic water injection" enables the control of the injected water depending on vibrations in combination with working pressure and resulting material bed height.

8 Outlook

The performance of a vertical roller mill is defined by a required throughput at a required fineness paired with a low specific thermal and electric energy consumption. Some areas in general need special attention: feed uniformity, metal detection and extraction, and preventive maintenance to name just a few. Operational parameters such as table speed, gas flow, working pressure and mechanical adjustments such as dam ring height and covering the nozzle ring are the levers to adjust for a well-performing vertical roller mill which is efficient in terms of electric and thermal energy.

Table 6: Properties of cements produced in MVR mills

Cement Type acc. to EN 197-1	Blaine value [cm²/g]	Normal consistency acc. to EN196-3 [%]	Strength acc. to EN 196-1 [MPa]	
			2 d	28 d
CEM I	3680	–	27.7	60.2
CEM I	5050	–	36.9	63.3
CEM I	4780	26.5	35.2	60.1
CEM I (3 mass % limestone)	5070	29.6	33.8	59.5
CEM I (3 mass % limestone)	5150	30.5	37.6	60.8
CEM I	5000	–	35.1	61.8
CEM I (5 mass % limestone)	3800	25.4	27.7	61.8
CEM I (0.5 mass % limestone)	3500	26.0	24.3	48.2
CEM I (5 mass % limestone)	4900	25.5	33.0	63.0
CEM II/A-L (17.5 mass % limestone)	4400	–	27.2	60.4
CEM II/B-P (28 mass % pozzolana)	4180	28.0	22.0	47.7
CEM II/B-M (12 mass % limestone, 12 mass % pozzolana, 2 mass % fly ash)	4140	–	20.0	57.2
CEM II/A-M (6 mass % limestone, 6 mass % pozzolana)	5130	–	29.4	56.3
CEM II/B-S (23 mass % GBFS, 4 mass % limestone)	4610	28.0	30.2	57.3
CEM III/A (45 mass % GBFS)	4450	29.5	17.0	52.0
CEM III/B (70 mass % GBFS)	5500	30.6	27.7	51.7

Support during commissioning in regard to the setting of operational parameters, reduction of stoppages and stable and smooth operation is very important. In addition to the above-listed setting of operational parameters and the GPpro or GPlink system, supplementary features such as "feed material detection" and "optimization by AI" can significantly support the achievement of a well-performing mill where energy efficiency is ensured. First trials with both features have shown very promising results and will be implemented in the future.

Not only the use of supplementary cementitious materials is an effective measure to reduce the CO_2 footprint, improving energy efficiency is also a key factor for grinding plants. In cement production more than 60 % of electricity is used for grinding of raw material and cement. With this huge amount it seems mandatory that energy efficient technologies should be used. State-of-the-art grinding technologies such as vertical roller mills can provide up to 70 % electricity savings compared to ball mill systems [11]. Other electricity saving strategies include cross-cutting measures such as upgraded cement process controls and the use of variable speed drives to run mechanical equipment across the site. This applies in particular for the main drive of the vertical roller mill and the main fan. The use of efficient grinding and milling technologies decreases the global electricity intensity of cement by 14 % by 2050 compared to 2014 in the 2DS [11]. The GPpro system has helped during the pandemic in 2020 to bring plants into operation. Commissioning was assisted from a distance where online meetings have been a big help as well. By providing additional pictures and movies from the plant sites the support could be targeted on specific topics.

All described features such as the design and wide range of duty series of the MVR mill, the flexibility when using clinker replacement materials, the performance of cement grinding and the overall innovative approach provide a very flexible system for the industry that is reliable in support of decreasing the CO_2 footprint of plants.

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