HPGR: WHY SKEWING IS A REQUIREMENT FOR OPERATIONAL APPLICATIONS

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Abstract

High pressure grinding rolls (HPGR) are an energy efficient solution for comminution of industrial minerals and metal ores. The technology is successfully applied in an expanding field of applications throughout the minerals industry. HPGRs compress and grind the particle bed in the operating gap between two counter-rotating rolls. The equipment provides a high capacity, low energy alternative for applications with conventional tertiary and quaternary crushing and grinding, with size reduction reaching from 100 mm feed down to 25 microns product. In this process, maintaining a controlled and evenly distributed operating pressure between the rolls is very important. Due to feed segregation, the pressure distribution along the roll's surface can become uneven, resulting in a coarser product. This paper will show that the pressure distribution can become severely uneven. As it is difficult to eliminate feed segregation, the HPGR design should compensate and adapt for the uneven pressure distribution as much as possible. This paper will present that the best approach to compensate and adapt for the uneven pressure is to allow the rolls to skew relative to each other. This will be further supported by operating data from operational HPGR installations. Coarser products are also caused by an inadequate pressure distribution: the much-discussed edge effect. To minimize the consequence of the edge effect, an optimized ratio for the roll length to roll diameter will be calculated. Furthermore, the design philosophy behind application of cheek plates will be detailed. This cheek plate is used to retain the material between the rolls, reducing the edge effect while still allowing roll skew. Together these design considerations help optimize HPGR's performance.

Keywords

High pressure grinding rolls, HPGR, roll skew, pressure distribution, edge effect, cheek plate, feed segregation, HPGR design

Introduction

Declining ore grades, difficult to process ores, and increasing energy costs continue to challenge the mining industry. High pressure grinding rolls (HPGR) are an energy efficient alternative to conventional crushing and grinding technologies that can help companies facing those challenges.

Contrary to popular belief, HPGR technology is not new, with first applications in the mid-1980s (Morley, 2010). While most applications can be found in cement, the applications in mining are increasing. Today, there are many successful applications in base metals, precious metals, and indGustrial minerals proving the reliability and energy efficiency HPGR.

The comminution process in an HPGR relies mainly on size reduction through to compression and inter-particle crushing in a particle bed in the operating gap between two counter-rotating rolls. The equipment typically has a high unit capacity and low energy consumption and is increasingly used as an alternative to conventional tertiary and quaternary crushing and grinding in particle sizes ranging from 100 mm down to 25 µm. It can be applied to moist ores and dry material, in open circuit arrangement, or in a closed circuit with dry or wet classification (screening, air classification) (Hannot, 2019).

For efficient operation of the HPGR, maintaining a controlled and evenly distributed operating pressure between the rolls is essential for ensuring product quality in terms of particle size distribution, and for optimizing operating cost in terms of minimum roll surface wear and minimum specific energy consumption. External factors, such as feed segregation, can lead to uneven pressure distribution and thereby a coarser HPGR product.

As it is difficult to eliminate external factors like feed segregation completely, the HPGR design should compensate and adapt for the uneven pressure distribution as much as possible. Keeping the rolls parallel in case of feed segregation over the width of the rolls would create high pressure on one side of the rolls, while lowering the local operating pressure on the other side. The lower pressure will lead to insufficient grinding, while the higher pressure might waste energy and lead to excessive wear on that side.

In order to deal with the uneven pressure, the rolls should be allowed to skew relative to each other. This will maintain the local operating pressure, satisfying a basic gap-pressure relationship and resulting in an evenly distributed pressure over the rolls' length, thus maintaining grinding conditions as determined by the operating pressure.

Low pressure zones exist on the edges of the rolls. To reduce these areas and ensure the material does not "escape" from the grinding zone, most HPGRs are designed with cheek plates. These close the operating gap at both sides of the rolls and prevent material from by-passing the process. The cheek plates not only reduce the edge effect; they are also specially designed to facilitate roll skew.

The following sections will detail considerations for the design and operating philosophy to optimize HPGR's performance in relation to roll skewing. Hannot presented some of the content of this paper in 2019.

HPGR Pressure Distribution

The size reduction in HPGR grinding is mainly achieved by interparticle crushing. A compact layer of particles is necessary as well as reaching a pressure exceeding the compressive strength of the material. Ideally, an even pressure distribution will ensure proper size reduction without wasting energy for exceeding the required pressure too much. An inappropriate design of HPGR or operating procedure can lead to areas on the tire surface where the required pressure is not reached, reducing the effectiveness of the comminution.

Two major causes of uneven pressure distribution are uneven feed to the HPGR and the edge effect. We discuss both phenomena in the following section.

EDGE EFFECT

The edge effect is the phenomena where the pressure in the HPGR gap will drop towards the edges, due to the tendency of the material to escape high pressure. In contrast to the center zone, the material closer to the edges might leave the gap between the rolls towards the sides instead of passing through the gap completely. Therefore, the HPGR discharge material coming from the edges tends to be coarser than the center product and it has fewer microcracks. Figure 1 shows a typical pressure profile over the width of a shallow laboratory HPGR tire without cheek plates, measured by Lubjuhn (1992).

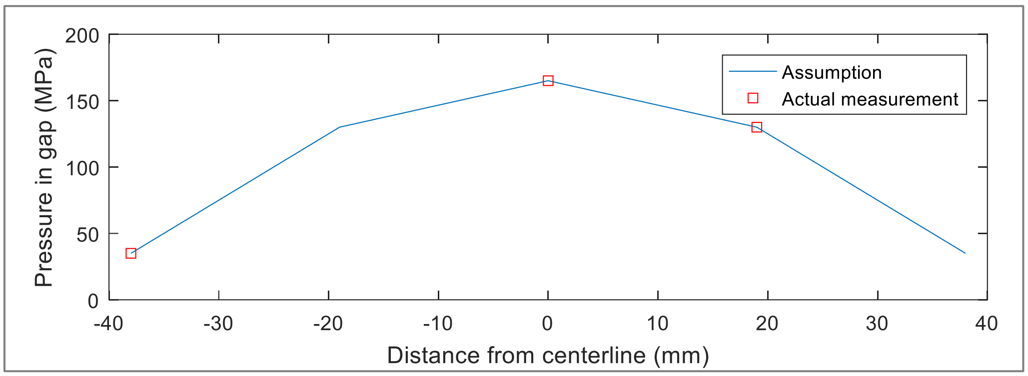

Figure 1 – Pressure in the Gap, Operating Gap 3 mm, Roll Width 100 mm, Roll Diameter 200 mm (adapted from Lubjuhn, 1992)

The exact shape of the pressure profile over the width of the tire cannot be drawn based on the Lubjuhn results, as only three positions were measured. However, the tendency of lower pressure towards the edges of a tire is clear and is in line with the day to day experience of operating an HPGR.

UNEVEN FEED MATERIAL DISTRIBUTION

A second reason for uneven pressure distribution is an uneven material distribution feeding towards the HPGR. Uneven feed can be a result of uneven mass or material properties, such as particles size or hardness.

In 2005, Cunningham published pressure profiles of a small laboratory HPGR fed by a screwed feeder. Some of the resulting profiles are shown in in Figure 2. The pressure peak moves over the width of the tire due to the uneven feed distribution originating from the screw feeder. The feed situation resulting from the screw feeder is an extreme example of an uneven feed that will not happen to the same extent in a full-scale mining application. However, it shows the sensitivity of the pressure profile to an uneven feed.

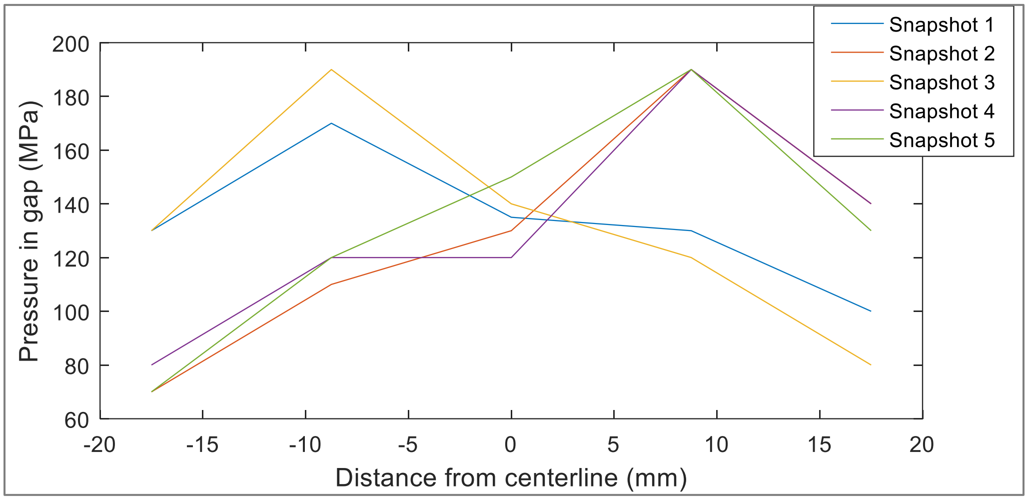

Figure 2 – Pressure in the Gap at Five Random Points in Time, Operating Gap 2 mm, Roll Width 35 mm, Roll Diameter 100 mm (adapted from Cunningham, 2005)

A second source of uneven feed to the HPGR can be segregation, where one side of the HPGR is mostly fed with coarser particles, while the other side receives more fines. Figure 3 shows a schematic illustration of feed segregation prior to the HPGR (Van der Meer & Maphosa, 2011). Similar to the impact of the uneven feed in the Cunningham experiments, feed segregation will lead to increased pressure on one side of the roller and low pressure on the other side. If the segregation remains over a longer period of time, it will also lead to an unfavourable and uneven wear pattern.

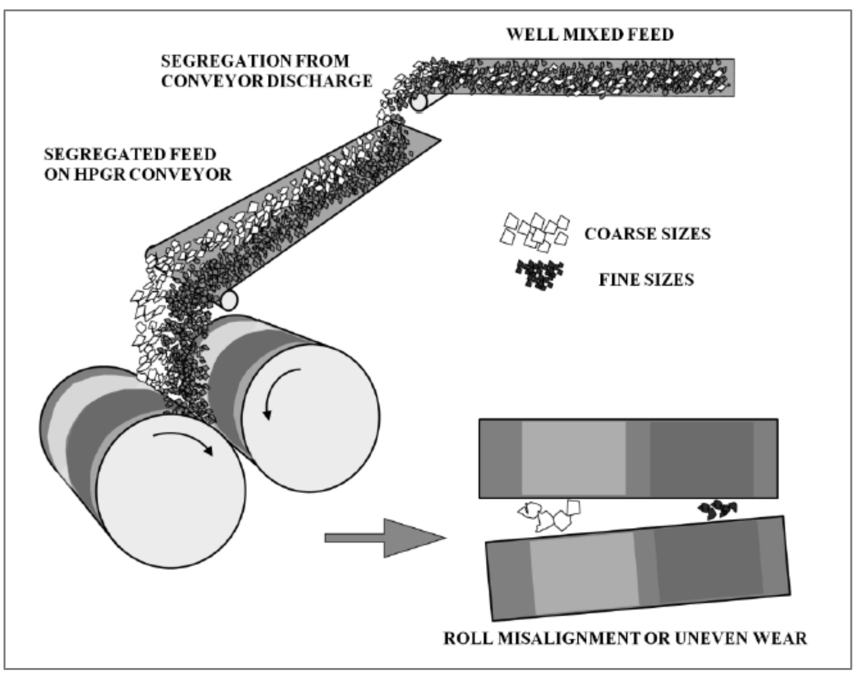

Figure 3 – Segregation of Feed Material Prior to the HPGR (Van der Meer & Maphosa, 2011)

Solutions

In order to cope with the challenges described in the previous section, several considerations have been made in the HPGR design. The following sections describe the design features and how they help mitigate the negative impact of edge effect and uneven pressure distribution.

CHEEK PLATES

Cheek plates, also called lateral walls, have the purpose of maintaining the material between the rollers and not allowing it to escape to the sides. This way the pressure-drop near the edge of the tire can be minimized.

The impact of cheek plates is already visible in some of the previous figures. Lubjuhn (1992) did not use cheek plates, resulting in an edge zone of more than five times the gap (Figure 1, total width 100 mm, gap 3 mm). Cunningham (2005) used cheek plates that helped to reduce the edge effect to three to four times the gap (Figure 2).

Figure 4 displays the results of a powder flow finite element simulation performed by Cunningham (2005), which underlines the impact of check plates. The zone where the edge effect is dominant is around 10 mm, which is in the range of three times the operating gap. The value of three times the operating gap as edge effect has proven itself reliable in daily operation over a wide range of HPGR sizes.

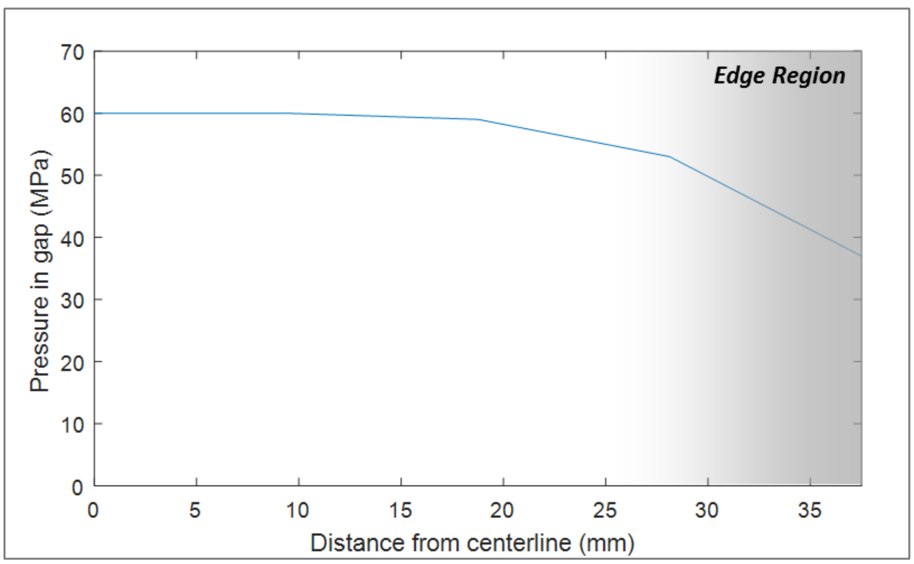

Figure 4 – Simulated Pressure of a Half Roller with Proper Edge Sealing, Operating Gap of 4 mm, Roll Width 70 mm, Diameter 200 mm (adapted from Cunningham, 2005)

Pilot scale trials on an Enduron® RP 2 80/25 investigated the impact of well-aligned cheek plates. The HPGR was operated with the normal, well-aligned cheek plates with a splitter below the HPGR, separating the discharge material coming from the center zone and the edge zone. Center and edge product were analyzed separately. The same test was repeated with artificially reduced performance of the cheek plates, by moving them 60 mm away from the side of the tire.

The resulting particle size distributions (PSDs) can be found in Figure 5. The center PSD of both setups was similar; however, the material discharged from the edge with well-aligned cheek plates was considerably finer than that without cheek plates.

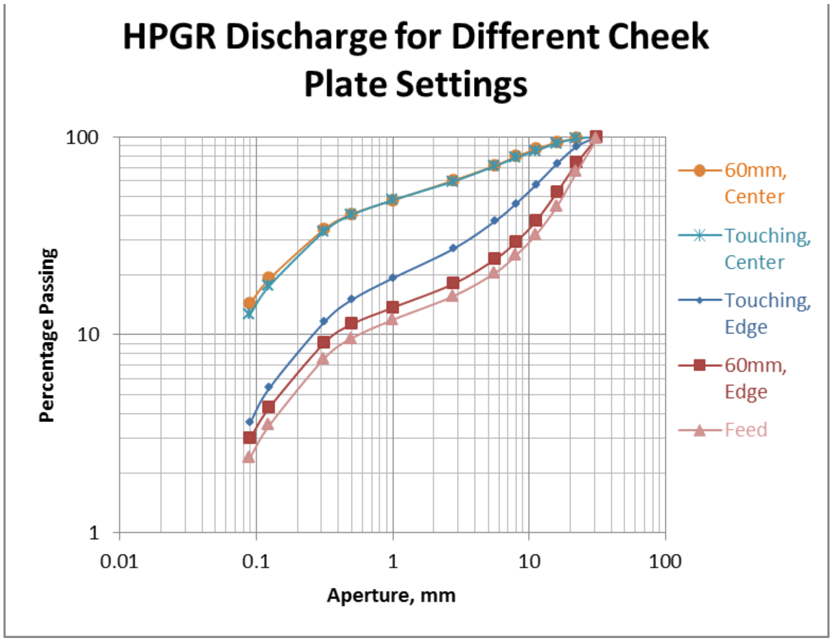

Figure 5 – Particle Size Distribution of HPGR Discharge for Check Plates Touching the Side of the Rollers and for 60 mm Gap Between Check Plates and Sides of Rollers

The spring-loaded design of the Enduron® HPGR cheek plates ensures a minimized gap between cheek plates and side of the tire but still allows for movement of the tire if needed. Figure 6 shows the Enduron® cheek plate and the interaction with the side of the tire.

Figure 6 – Enduron® Spring Loaded Cheek Plate; left: A Cheek Plate System Before Installation; Middle: Tip of the Cheek Plate Installed; Right: Side View of Space Between Roller And Cheek Plate

L/D RATIO

The ratio between length (L) and diameter (D) of an HPGR roller has great impact on the resulting product and the performance of the HPGR. When selecting the dimensions for an HPGR roller, several considerations must be taken into account. There are three parameters that will remain constant when determining the dimensions of an HPGR:

- A desired mass flow → Q [tonnes/hour]
- A known specific throughput → SPT [(tonnes/hour) / (m^3/s)]
- A known required grinding pressure (also known as specific grinding force) → Fsp [N/mm^2].

The variables that can be selected during the design process are assumed to be:

- The roll diameter → D [m]
- The roll length → L [m]
- The roll speed → ω [rad/s] or n [rpm].

The relation between the above-mentioned parameters is the classic specific throughput formula:

$$Q = SPT \cdot D \cdot L \cdot v = SPT \cdot \frac{1}{2} \cdot D^2 \cdot L \cdot \omega \qquad \text{(Eq. 1)}$$

Here v = ½ D ω is the circumferential velocity of the roll. When sizing an HPGR, the velocity might change but ω will remain constant. As described in the previous section, the size of the edge zone is mostly related to the gap between the rollers. Historical testwork data shows that the gap is directly related to the diameter of the roller, thus the size of the edge zone is also related to the diameter (Van der Meer, 2010 & Klymowsky et al., 2002)

Figure 7 shows a collection of historical testwork data for a multitude of ore types, particle sizes, and settings, where the gap is shown as a percentage of the rolls' diameter. It is visible that despite some scattering, a value around 2.5% of the diameter is a close estimation of the gap.

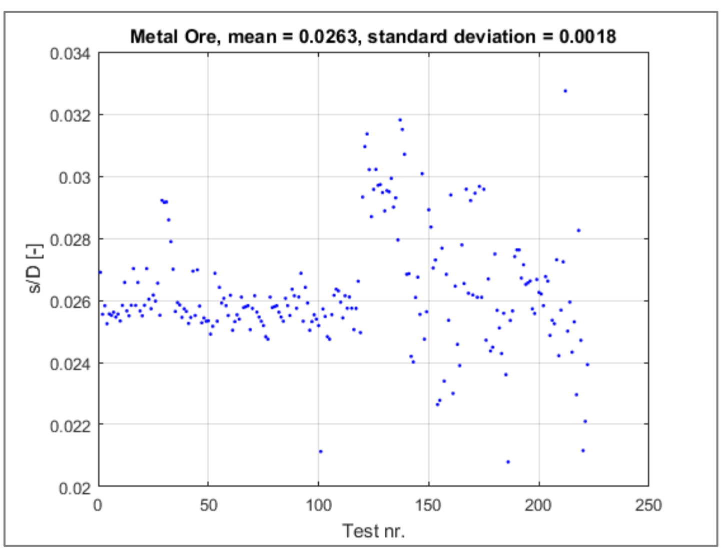

Figure 7 – Ratio of s/D for a Certain Ore Type for those Tests where: 4 <Fsp <6 N/mm^2

Explained earlier and visible in Figure 5, the product coming from the edge area of the roller is considerably coarser than that coming from the center area. For further design considerations, the grinding in the edge zone is considered insufficient and the edge material needs further size reduction. Therefore, the edge material needs to be sent back to the HPGR and only the center material is allowed to pass to the next stage of processing. As a result, the total energy consumption per tonne of product passing on to the next stage of processing will be higher in those cases where more edge product is present. Figure 8 illustrates the normalized energy consumption per tonne of product passing on to the next stage of processing as a function of the L/D ratio.

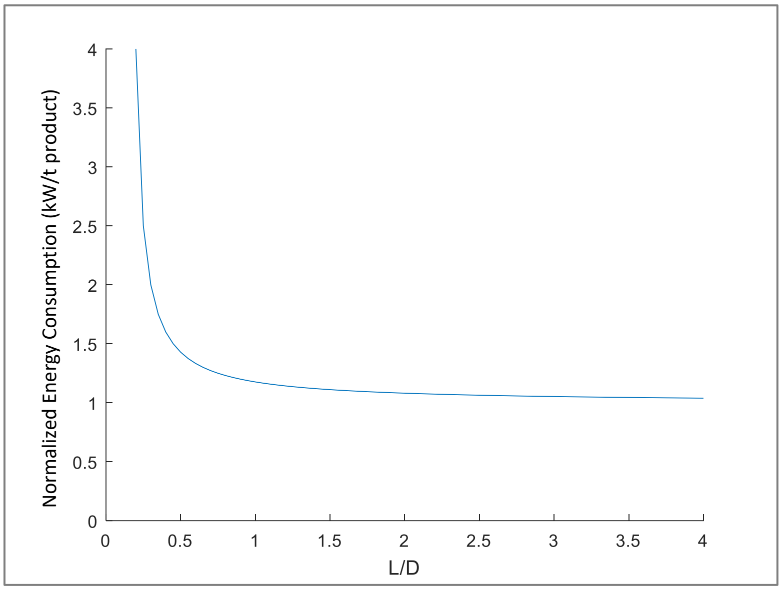

Figure 8 – Normalized Energy Consumption per Tonne Material as Function of L/D

It is apparent that large L/D ratios are favourable and lead to lower overall energy consumption per tonne of product for a given pressing force. For large L/D ratios, practical issues arise that might limit the operational flexibility and limit the possibility of the roller to move when needed. Therefore, an L/D ratio around or just over one seems to be the best compromise between operational practicality and low energy consumption.

SKEWING

Uniform and even pressure distribution over the complete width of the tire is necessary to achieve ideal grinding results. As discussed earlier, these ideal grinding results are not perfectly achievable in an operational HPGR for several reasons. Allowing one roller of the HPGR to move when needed helps to get closer to the ideal operation and allows dealing with uneven feed. This ability to move is called skewing.

Figure 9 illustrates the principle of skewing and how it helps to maintain an even pressure distribution despite uneven feed conditions. An even feed will result in an even pressure distribution, only dropping towards the edges. If the feed to the HPGR becomes uneven or segregated, a system without skewing will lead to local high pressure on one side and low pressure on the other side of the roller. Skewing allows for a smaller gap on one side and a larger gap on the other side, while still maintaining an even pressure distribution. There are limits to the extent and duration of skewing that is accepted, which is managed by a control system.

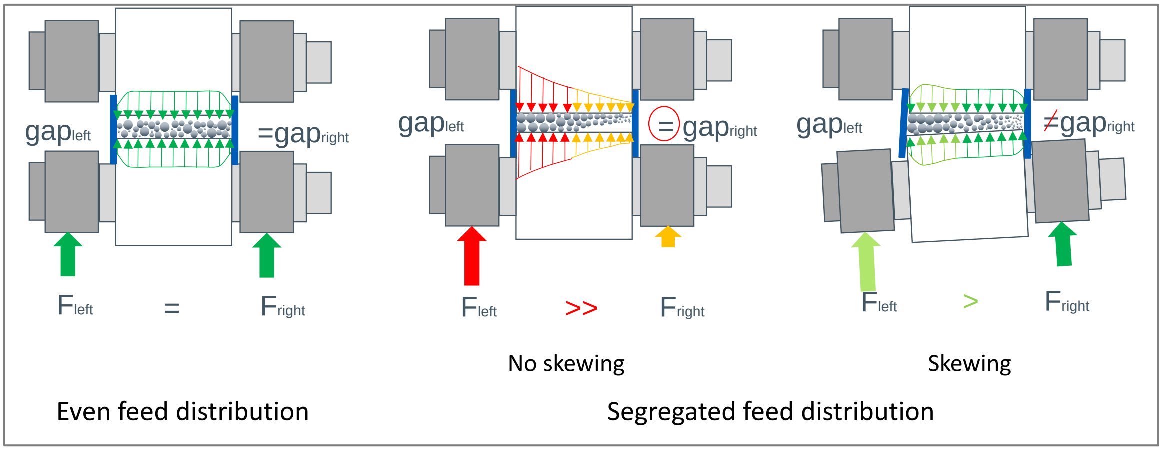

Figure 9 – Top View of an HPGR to Illustrate the Principle of Skewing

Figure 10 illustrates an example of skewing in an industrial HPGR. The operational data shows that the control system constantly allows for some skewing in high frequency events as well as more slow variations in the range of 10 minutes. The high, frequent variations are most likely caused by coarser particles entering the HPGR; the slower changes are most likely caused by non-permanent segregation. The system is performing well on this HPGR because the average skewing is close to zero over a longer period of time. The difference between the hydraulic pressures on both sides of the roll (differential pressure) is also averaging around zero over a longer period of time.

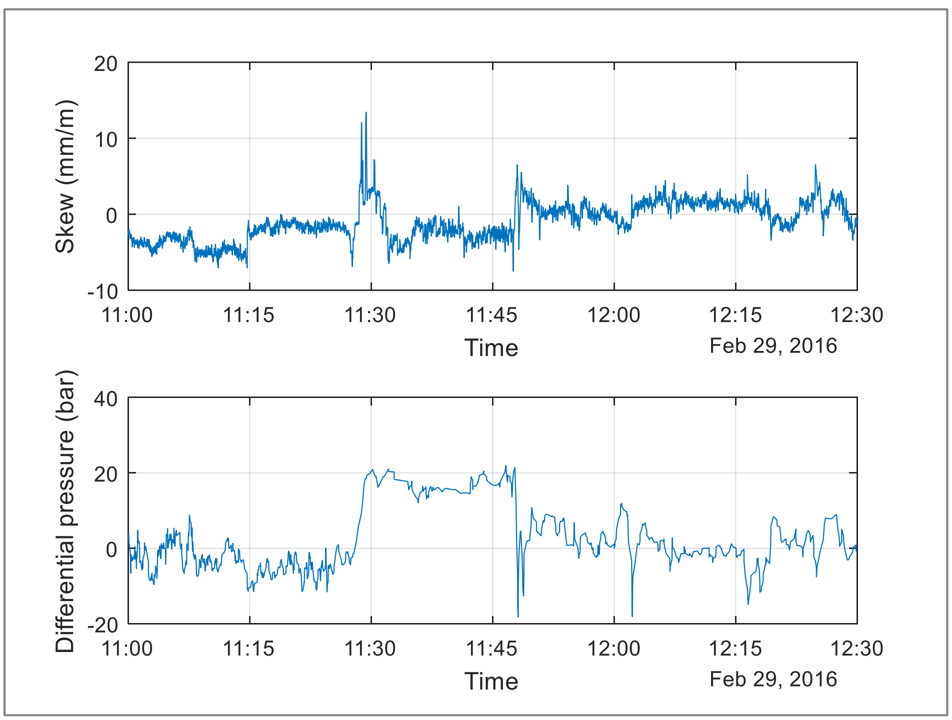

Figure 10 – Operation Skewing Data for a Midsize WEIR Enduron HPGR

Conclusions

Allowing for an even pressure distribution over the length of the rollers is key for good HPGR performance where typical variation in feed conditions and size distribution occurs. However, uneven feed and edge effects can lead to an uneven pressure distribution resulting in reduced performance.

Cheek plates, also called lateral walls, aim to minimize the pressure drop near the edge of the roller and avoid material physically bypassing the HPGR process. Without cheek plates the coarseness of the product increases, and lateral roll wear increases due to the material flowing out of the central high compression zone. Enduron® HPGR tires, in combination with spring loaded Enduron® HPGR cheek plates, minimize the gap between cheek plate and roller, while still allowing the roller to skew.

We have illustrated that a higher L/D ratio leads to reduction in the percentage of edge material exiting the HPGR. Based on a mathematical approach, the energy consumption per tonne of product was calculated as a function of the L/D ratio. This shows that a large L/D ratio is beneficial in terms of energy consumption. From a practical point of view, L/D ratios around one are the best balance between reducing the edge effect and maintaining a good skewing system.

Differences in the feed properties over the length of the roll will lead to local differences in the pressure conditions. Wear will be extensive in high pressure areas while the grinding will be insufficient in areas of low pressure. In case of uneven pressure distribution, the rolls should be allowed to skew to achieve and maintain the operating pressure required for optimum grinding performance over the complete surface of the roll. This is the preferred option, as opposed to maintaining a parallel roll alignment, which would sustain a differential pressure over the length of the rolls and result in off-spec product size distribution and uneven roll surface wear.

Especially for larger (wider) rolls, skewing generally results in only a relatively small operating gap difference (±5 mm/m of full roll width). The effect on local pressure peaks can be significant. To limit skewing within an acceptable range, an advanced control system should be in place, which steers the rolls' position to satisfy the desired pressure profile. This also provides a signal to the supervising control system and operating staff in case of a prolonged or excessive skewing. Prolonged skewing generally is indicative of a disturbance or fault in up-stream facilities (such as low bunker filling, upstream crusher wear, screen deck wear, or conveyor failure).

All of the described design features are necessary to ensure a nice performance of the HPGR even in the challenging and changing environment of mining and mineral processing.

References

Cunningham, J. C. (2005). *Experimental studies and modelling of the roller compaction of pharmaceutical powders* (Unpublished PhD Thesis). Drexel University, Philadelphia, PA.

Hannot, S. D. A., Van der Meer, F. P., & Knapp, H. (2019). *HPGR: Why skewing is a requirement for operational applications*. 51th Annual Meeting of the Canadian Mineral Processors, Ottawa, 2019.

Klymowsky, R., Patzelt, N., Knecht, J., & Burchardt, E. (2002). *Selection and Sizing of High Pressure Grinding Rolls*. SME Conference, Vancouver, 2002.

Lubjuhn, U. (1992). *Materialtransport und Druckverteilung im Spalt der Gutbett-Walzenmühle* (Unpublished PhD thesis TU Clausthal). TU Clausthal, Düsseldorf, Germany.

Morley, C. (2010). HPGR – FAQ. *The Journal of The Southern African Institute of Mining and Metallurgy*, Vol. 110, p.107-115.

Van der Meer, F. (2010). *High pressure grinding rolls scale-up and experiences*. In XXV International Mineral Processing Congress (IMPC) 2010 Proceedings, Brisbane, QLD, Australia, Paper (Vol. 194).

Van der Meer, F., Maphosa, W. (2011). High pressure grinding moving ahead in copper, iron, and gold processing, *The Journal of The Southern African Institute of Mining and Metallurgy*, Vol. 112, p.637-647.