ThyssenKrupp Polysius

High Pressure Grinding Rolls for Minerals

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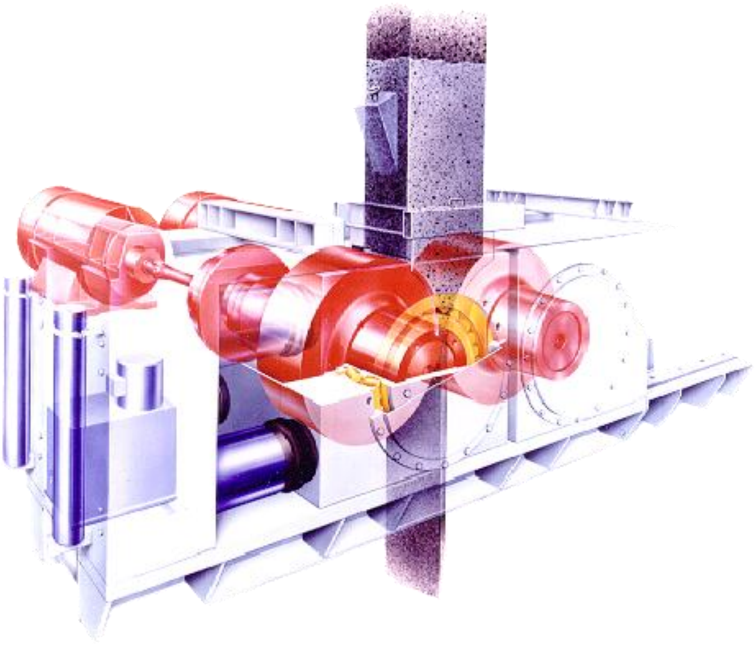
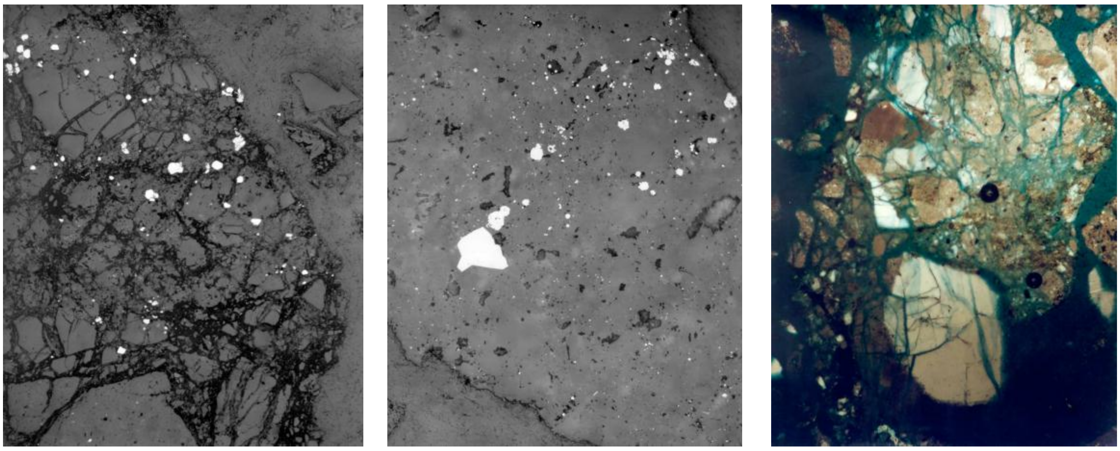




1. Introduction

High Pressure Grinding Rolls have been used for the grinding of diamond and iron ores since about 1988. There are now about 40 machines operating world-wide in these industries. This number is still small in comparison to the > 450 machines employed in the cement and raw materials industry. In the diamond industry, the machines are used mainly for secondary and re-crush duty. In the iron ore industry, most of the machines are found in pellet feed applications. However, there are a few notable examples where HPGRs are used for coarse iron ore grinding – in Chile, Mauritania and the USA. The first large scale attempt at applying HPGRs to harder and more abrasive copper and gold ores was in 1996 at Sierrita. Although this was considered a failure by many in the industry, valuable lessons were learnt with regards to what type of surface would be best suited to protect the rolls against wear from hard abrasive ores, and what design and layout would be optimum for rapid roll change-out. Now in 2003, there is currently a new large scale test being conducted on a hard abrasive gold ore, putting the lessons learnt into practice.

The early machines were equipped with smooth Ni-Hard or welded hard metal surfaces. These suffered from high wear, but the wear was manageable and many machine continue to operate to-date with these surfaces. Studs were introduced in 1989 for the grinding of chromite concentrate in Finland. The development of studded wear surfaces was an important milestone for the move of HPGRs into minerals. Some of the earlier diamond machines have now been refitted with studded surfaces, and the results have been remarkable.

The next improvement in wear protection was the introduction of replaceable studs and the development of side protection to eliminate welding. Welding is the major cause of downtime for the machines. With these improvements one can now count on availabilities > 94%.

So what is holding up the application of HPGRs in copper and gold? My guess is that no one wants to be first. People have to be convinced that the wear problems have been solved. The risk of applying new technology has to be off-set by a significant reduction in capital and operating costs compared with conventional methods of size reduction.

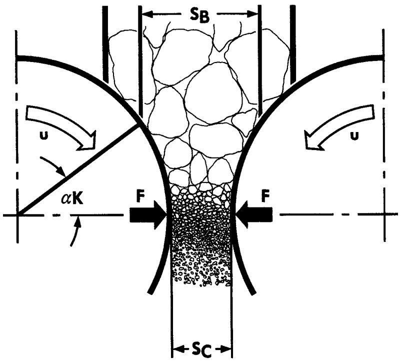
This paper discusses wear and the measures taken to overcome this problem; availability and the procedures implemented to reduce downtime for replacement of the rolls; criteria for selection and sizing of HPGRs; describes where they may be used in mineral processing circuits and gives an order of magnitude estimate of the savings that may be expected.

2. Description of a HPGR

A HPGR is principally a horizontally mounted double-roll mill, equipped with hydraulic pistons on one side, pressing against the floating roll - the other roll being fixed in the frame. The main components of the machine are of course the rolls, the bearings, frame, pressure beams, hydraulic system, drive system, lubrication and cooling systems, and the feed chute.

Feed is introduced into the gap between the rolls in a choke-feed manner, and is comminuted by a mechanism of interparticle breakage.

Feed coarser than the gap is broken by nipping. The degree of comminution achieved is determined by the pressure applied to the rolls. Pressures in the gap may range from 50 to 250 Mpa. Forces vary with the diameter of the rolls from about 750-20,000 kN (75 - 2000 to). For orientation purposes, the compressive strengths of most hard ores lie in the range of 180-240 Mpa. The force required for the breakage of particles < 60 mm is usually < 100 kN.



Interparticle breakage

Roll diameters vary from 0.5 m to 2.8 m, and roll widths vary from 0.2 m to 1.8 m. The recommended maximum L/D ratio for hard ores is 0.7:1. The L/D ratio has a very important effect on the properties of the mechanical components, layout of the drive system, performance of the rolls and wear life of the liners. Capacities vary from 20 to > 2500 t/h. Installed motor power, from 2 x 50 kW to 2 x 3000 kW.

The rolls are protected from wear by thick wear resistant liners, and the ore is contained within the rolls by cheek plates. The type of liners recommended for hard abrasive ores are shrink-fitted tyres equipped with tungsten carbide studs. The thickness of the liners, cheek plates, types of studs used, and ease of replacement of these parts varies with the supplier. In some cases, for very abrasive ores, it may be preferable to employ rock boxes instead of cheek plates – although these cases are fewer in light of the development of special new side protection systems.

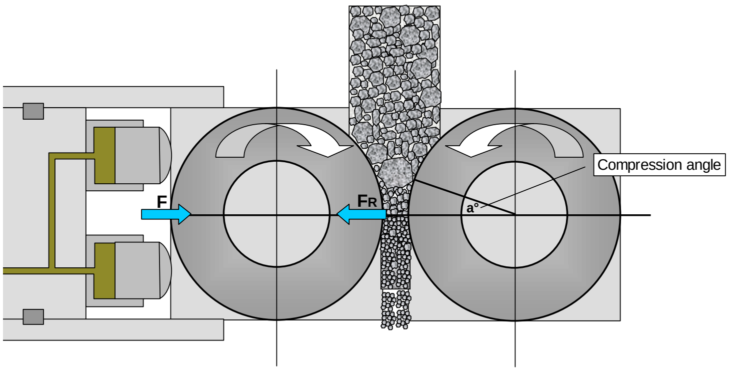
The characteristics of high pressure grinding rolls are :

- energy efficiency
- high and steady throughputs
- low space requirement, compact design
- lower capital & operating costs than conventional equipment of comparable performance
- low installation costs
- low dust & noise levels
- rapid start-up to full capacity
- simple push button control.

Control is system of interlocks to start the machine, monitor it during operation, to adjust the pressure to a pre-set level, and to prevent skewing of the rolls from exceeding certain limits.

3. Common misconceptions about HPGRs

Misconception 1. “The gap between the rolls is fixed”. One of the commonest misapprehensions is that the gap between the rolls is fixed and that 50 mm particles can be broken to < 2 mm in one pass. Unlike in conventional rolls, the gap is not fixed, but varies slightly according to the nip-in characteristics of the material. The size of the gap is determined by the balance between the reaction force from material in the gap, as it is compacted to its ultimate density (85-88% of its true density), and the compressive force applied to the rolls by the hydraulic pistons. Gaps vary directly with the size of the rolls, and for coarse, dry material, are typically between 2.0 - 2.5% of roll diameter. Fine products require screening.



Misconception 2. “Rolls are not suitable for the treatment of highly weathered ores or feed containing a large proportion of fines or moisture”. HPGRs are used in the diamond industry for treating soft, sticky material containing up to 16% moisture; and in the iron ore industry for the preparation of pellet feed (< 100 µm) containing up to 12% moisture. HPGRs have also been tested on bauxites and Ni-laterites. They are more tolerant to fines and moisture than conventional cone crushers. However, it is always better to remove excessive amounts of clay minerals and free moisture by scrubbing (or filtering) prior to HPGR treatment.

Misconception 3. “Any size and any tonnage can be put through the rolls”. The optimum top size for the HPGR is about the size of the gap. This limit is imposed on studded rolls in order to prevent stud breakage. Smooth or profiled rolls can tolerate larger sizes – however at the expense of wear. For optimum grinding effect, the rolls should be choke-fed. Underfeeding the rolls reduces breakage and causes excessive wear at the center of the rolls.

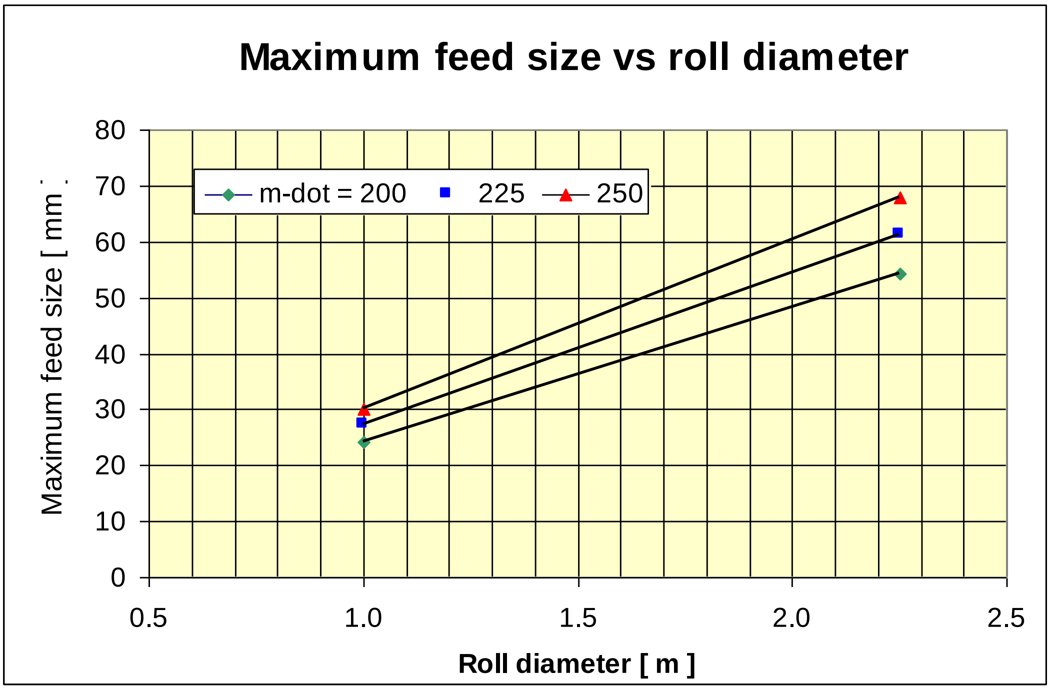
Misconception 4. “It is more efficient to grind truncated feed than full feed size distributions”. To-date most of these observations are derived from tests of pilot size units, where there is a considerable amount of pre-breakage of sizes coarser than the gap. Pre-breakage masks the overall grinding effect. Analysis of results on larger rolls with larger gaps has shown the opposite effect. The throughput on a truncated feed is 20% lower; specific energy consumption is then 25% higher, however the overall amount of fines obtained (through pre-screening and HPGR) is not 25% higher. Thus treatment of truncated feed is not more energy efficient. Furthermore, the absence of fines in truncated feed increase the wear considerably.

Misconception 5. “Product is always in the form of flakes which require disagglomeration”. Most siliceous ores do not produce flakes, and the flakes that are produced tend to break up easily on handling and screening. It is rare that disagglomeration is required. The recycling of oversize increases the capacity of the rolls, often by 20-30%. Thus a certain amount of screen inefficiency can be accommodated, without requiring larger size rolls.

Misconception 6. "Increasing the pressure will result in a proportional increase in fines". Increasing pressure results in a proportional increase in specific energy consumption. However, above a certain limit, the increase in fines production is very small - with the energy going into compaction of the flake. It is frequently more energy efficient to operate a HPGR at lower pressures and in closed-circuit with a screen, than wasting energy on compaction.

Misconception 7. "The Bond formula is applicable to HPGRs". In fact, the size reduction in HPGRs follows Rittinger's law of the creation of new surface area more closely. Plotting energy consumption vs the d_{50} size results in a negative slope of 1. The products from widely differing size distributions are often very similar. Furthermore, the use of the Bond formula d_{80} size does not adequately account for the higher amount of fines produced by the HPGR.

Misconception 8. "All HPGRs are the same and all suppliers are up to speed in this technology". The rolls differ in design, e.g. L/D ratio, bearings employed, safety factors applied to the components, ease of roll replacement, and especially in wear protection. In the last few years, POLYSIUS has concentrated on developing the rolls for the gold and copper mineral industries, raising the availability to > 94% to match those of SAG mills. The large scale test currently being conducted on a hard abrasive gold ore will prove that this technology is now ready to challenge conventional circuit design.



4. Key Terms and Parameters

Two terms are particular to HPGRs: the specific throughput and the specific press force.

The **specific throughput**, $\dot{m}$, is defined as the throughput [t/h] divided by the diameter [m], width [m] and speed of the rolls [m/s], and is a measure of the nip-in characteristics of the rolls. The units are given in ts/hm³, and the value can be determined from any size of rolls equipped with a similar surface from equation (1). It is the key parameter for sizing the rolls.

$$\dot{m} = \frac{M}{D \cdot L \cdot u} \qquad (1)$$

where,

M is the throughput rate, in t/h
D is the roll diameter, in m
L is the roll width, in m
u is the roll speed, in m/s

$\dot{m}$ has units of ts/hm³.

Factors affecting the specific throughput are: the size distribution, (x_{max} to gap size ratio), moisture, bulk density of the material, pressure applied to the rolls and the speed of the rolls. The maximum effect of any one of these factors is about ± 20%. The factor having the largest effect is the type of roll surface employed (e.g., smooth, or studded).

The throughput can also be calculated from the continuity equation as follows:

$$M = L \cdot s \cdot u \cdot \rho_c \cdot 3.6 \qquad (1b)$$

where,

s is the operating gap, in mm
ρ_c is the density of the cake, in t/m³.

Combining equations (1) and (1b), one obtains:

$$\dot{m} = (s/D) \cdot \rho_c \cdot 3.6 \, . \qquad (1c)$$

For scale-up purposes it is assumed that, for a given material and operating conditions, the gap scales linearly with the diameter of the rolls, and the specific throughput can be assumed to be constant.

The **specific press force** is defined as the grinding force applied to the rolls [kN] divided by the diameter [m] and width [m] of the rolls. It has units of N/mm², equation (2).

$$Fsp = \frac{F}{1000 \cdot D \cdot L} \qquad (2)$$

where,

F is the grinding force applied, in kN
D is the roll diameter, in m
L is the roll width, in m

Fsp has units of N/mm².

The grinding pressure applied to the material bed between the rolls controls the product fineness. The specific press force is a convenient way of expressing this pressure, as well as of comparing the grinding forces between different sizes of HPGRs. The values of the specific press force range from about 2 – 5 N/mm² (for studded rolls).

The **maximum pressure** applied to the material between the rolls has been estimated at about 40-60 times this value. Prof. Schönert gives a formula for the maximum pressure:

(3) $$P_{max} = \frac{F}{1000 \cdot D \cdot L \cdot k \cdot \alpha_{ip}}$$ where,

F	is the grinding force applied, in kN
D	is the roll diameter, in m
L	is the roll width, in m
k	is a material constant (0.18-0.23)
α_{ip}	is the compression angle (6-10°)

Pmax has units of Mpa or [N/mm²].

The angle of compression, α_{ip}, can be calculated from the operating gap as follows:

$$\cos \alpha_{ip} = \frac{\frac{1}{2} D - \frac{1}{2}(s_o - s)}{\frac{1}{2} D} = 1 - \frac{(s_o - s)}{D}$$

From the continuity equation: $M = L \cdot s_o \cdot u \cdot \rho_b \cdot 3.6 = L \cdot s \cdot u \cdot \rho_c \cdot 3.6$

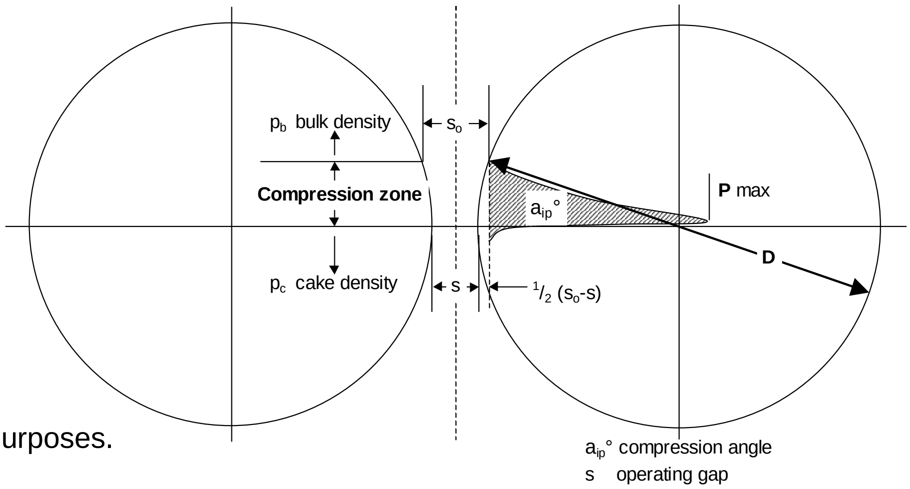
$$s_o = \frac{s \cdot \rho_c}{\rho_b}$$

By substitution:

$$\cos \alpha_{ip} = 1 - \frac{s}{D} \cdot \left[\frac{\rho_c}{\rho_b} - 1\right]$$

$$\text{and } \alpha_{ip} = \sqrt{\frac{2s}{D} \cdot \left[\frac{\rho_c}{\rho_b} - 1\right]}$$

$P_{max} \propto \frac{F}{\sqrt{s}}$, which can then be used for control purposes.



The **specific energy** consumption of a HPGR is determined from the total net power [kW] required to turn the rolls divided by the throughput [t/h], and is expressed in kWh/t. It is proportional to the specific press force applied to the rolls, and ranges from 1.5 – 2.5 kWh/t (for studded rolls).

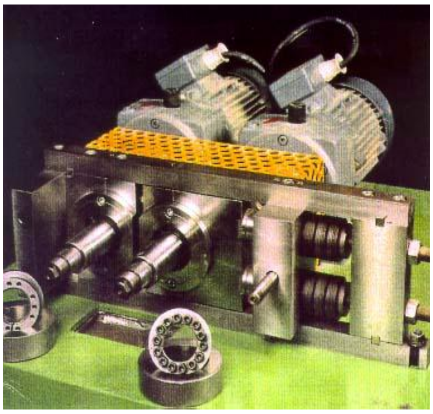
(4) Wsp = P [kW] / M [t/h] where, Wsp is the specific energy consumption

Each roll is driven by a separate motor. The minimum motor power required is determined by multiplying ½ the net power required by a factor of 1.15 to account for any unevenness in the power draw of each roll. The final motor power is determined by the maximum power that can be transmitted to the rolls by the gear boxes fitted to the shafts.

5. Wear

Wear is perhaps the most important concern with regards to the application of HPGRs. Wear is a function of the:

- Abrasiveness of the ore
  moisture and size distribution
- ➢ Composition of the studs and liners
  pattern and density of the studs
  length and design of the studs
- Susceptibility to breakage
- ➢ Diameter of the rolls
- ➢ Speed of the rolls
- ➢ Pressure applied
- Uneven power draw of the motors
- Skewing due to feed segregation
  or uneven distribution of feed across rolls that are too wide.



ATWAL Wear testing unit

The abrasiveness of an ore can be tested on a small laboratory rolls unit – ATWAL – and the wear life of the rolls can be predicted from the results. In general, the abrasiveness of an ore <u>increases</u> with hardness. Gold ores are about twice as abrasive as copper ores; copper ores are more abrasive than iron ores; and diamond ores range across a wide spectrum. Wear increases with moisture, and in the absence of fines. The increase in the wear rate with moisture and with coarse feed with narrow size distributions (truncated feed) may be as much as four-fold.

The studs used on HPGRs have an Rockwell HRA hardness of 85-92. They vary in compressive strength over a range of at least 50%, and in fracture toughness over a range of 100%. The objective is to draw a balance between wear resistance and resistance to stud breakage. Stud breakage is usually caused by tramp metal. Stud breakage can cause very rapid wear in localized areas. Thus the possibility of replacing broken studs rapidly becomes rather important.

Proper housekeeping and the use of magnets and metal detectors can do much to reduce tramp metal. Also the design of the studs can be improved to reduce the potential for stud breakage, and allow harder materials to be used.

Other factors affecting wear are the diameter, speed, and the pressure applied to the rolls. Rolls with a high aspect ratio – larger diameter, smaller width - have a longer wear life. This can be illustrated by the following example. Two HPGRs are compared, each with the same throughput. One has a low aspect ratio – diameter 1.7 m, width 1.8 m; the other, a high aspect ratio – diameter 2.25 m, width 1.4 m. Both represent the largest models installed. The first model, with the low aspect ratio has to be operated at a higher speed to reach the same throughput. As the wear life is determined by the thickness of the layer worn off per revolution and the roll speed, it follows that the rolls with the larger diameter would have the longer wear life – 36%. In fact, the wear life of the larger diameter rolls would be even higher due to lower slip at the lower speed, better nip and larger gap. The wear life of these rolls could be 40-45% longer. The cost savings can be quite significant.

			Small D	**Large D**
Aspect ratio			**Low**	**High**
Roll diameter	D	[m]	1,70	2,25
Roll width	L	[m]	1,80	1,40
Roll speed	n	[rpm]	23,26	17,06
Relative throughput		[%]	100	100
Recommended motor power	2 x P_{rec}	[kW]	1.575	1.575
Relative gap size		[%]	100	132
Relative liner life		[%]	100	136

Example illustrating the longer wear life of larger diameter (high aspect ratio) rolls.

The wear costs are largely determined by the wear life of the liners. In iron ore pellet feed applications, the wear lives range from 8,000-14,000 h. For coarse iron ores, the range is from 6,000-10,000 h. For diamond ores, the range is from 3,700-9,000 h (on studded rolls). For copper and gold ores, the range is from 2,000-6,000 h. The critical point is at about 3000 h, below which the costs begin to rise rapidly. For highly abrasive ores, every effort should be made to stretch the wear life of the rolls, and increase availability, beyond this critical point. This includes:

1) attention to feeding - that the rolls are always choke fed; avoidance of segregation in the feed; and uniform distribution of the feed across the width of the rolls.
2) proper design of feed hoppers - to avoid blockage and build-up of material on the hopper walls.
3) selection of the optimum zero gap, N_2 spring characteristic & operating pressure.
4) ensuring an even power draw on the motors – by employing torque control on variable speed drives.

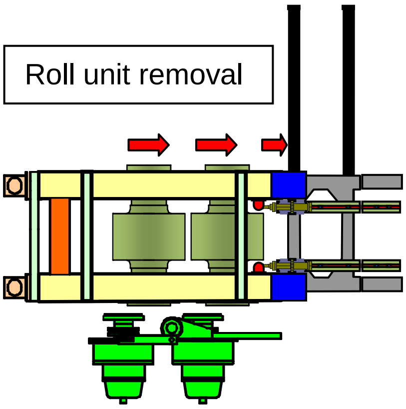
6. Availability

The mechanical availability of a HPGR is very high, 99%. The operating availability is chiefly related to the wear of the roll surface, wear on the sides of the rolls, and time required to change-out the rolls. One can now claim operating availabilities in excess of 96%.

The wear of the surface can be minimised as discussed earlier, by proper selection of studs and operating conditions. The sides of the rolls can be protected from wear for the lifetime of the rolls by employing special side protection – thus eliminating the need for welding. Several types of side protection have been developed and are currently being tested. Cheek plates have been designed of extra thick wear material, and can be changed out quickly - in a matter of hours.

The roll units can be changed out in < 30 hours, without the need for removing the feed hopper or for an overhead crane.

This rapid change-out procedure has been made possible by designing the rolls such that the roll units (rolls & bearings) can be uncoupled from the drives and slid out from one end onto a platform or dolly for removal and replacement with a new set of roll units.



7. Potential Applications

Some potential applications of HPGRs in copper and gold are in:

1) Pebble crushing in SAG mill circuits – to increase the capacity of the circuits
2) Upgrades of conventional crushing and grinding circuits
3) New installations – as an alternative to SABC circuits
4) Heap leaching operations.

1) HPGRs in pebble crushing.

These circuits are characterised by unsteady feed to the pebble crushers, harder material, presence of tramp metal and oversize. Most operations recognise these problems and take various precautions to overcome tramp (grizzlies, magnets, metal detectors and tramp diversion chutes). The feed to the HPGR can be steadied by employing variable speed drives, but some cases may call for a surge bin ahead of the HPGR. Given that these problems can be overcome, the HPGR can provide an increase in capacity of the SAG mills of 15-30%.

The reason lies in the fact that the HPGR product is precisely tuned to the size range where the SAG mill has its highest grinding efficiency. The productivity of the SAG mill can further be enhanced by screening out the fines in the HPGR product.

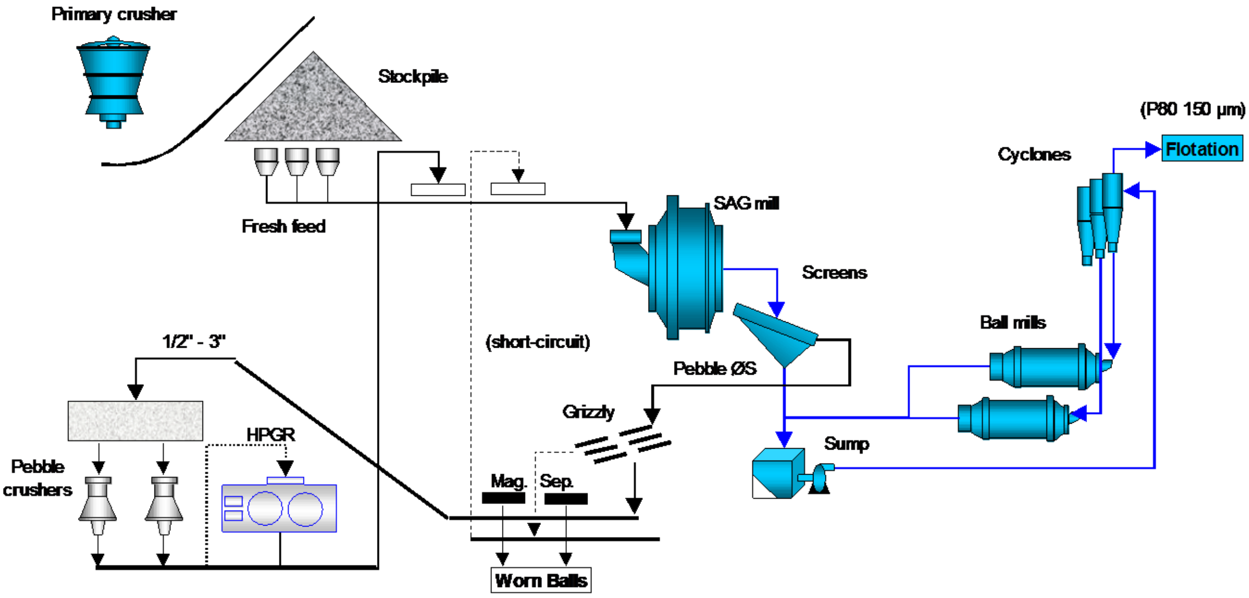


Figure 7.1 SABC circuit with HPGR for pebble crushing.

The maximum permissible size for the HPGR in these applications is about 31.5 mm (1 ¼”). As the size of the pebbles is often up to 90 mm (3 ½”), cone crushing is required before the HPGR. Typical product size distributions are shown in Figure 7.2.

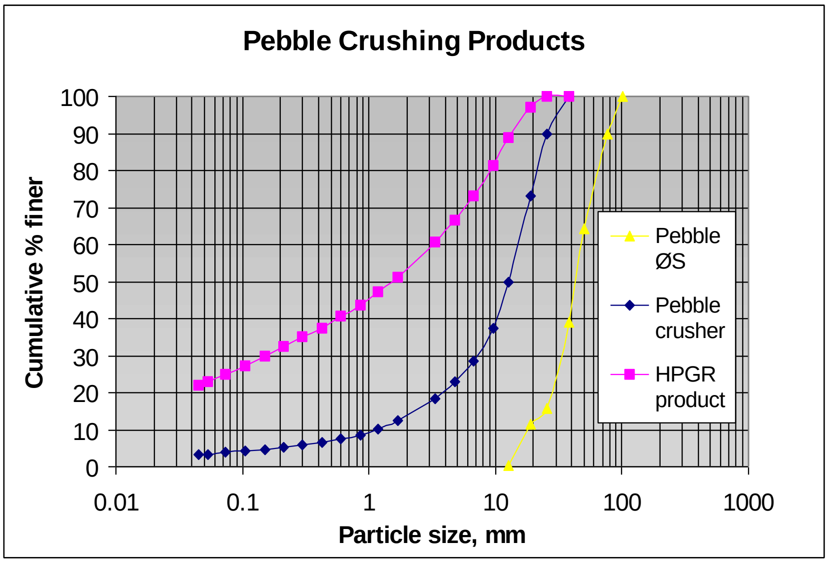


Figure 7.2 Pebble crushing product size distributions.

2) Upgrades of conventional crushing circuits.

The example shown here is of a three-stage crushing plant producing a 5.0-7.0 mm product at a rate of 15,000 t/d. The ore is very hard, WI > 23 kWh/t. The plant consists of a primary crusher, scalping screens, one secondary crusher, product screens and three tertiary crushers. The main bottleneck is the tertiary crushers, which have difficulty maintaining the finer size. The objective was to double the capacity of the plant, while maintaining a finer product.

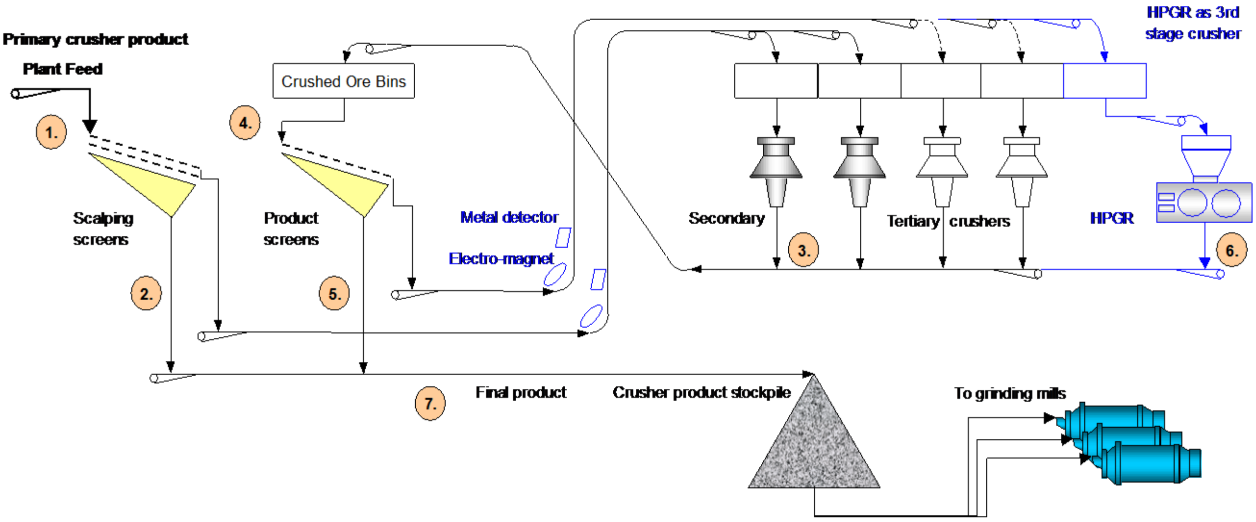


Figure 7.3 Crushing circuit with HPGR as 3rd stage.

Introducing a HPGR as a tertiary crusher, it is possible to place two of the tertiary crushers on standby, use one as a secondary, and increase the capacity of the circuit by 100%. This arrangement would cause minimum disruption to the existing operation, and would be easiest to implement. The availability would also be increased.

The capital investment for a HPGR (850 t/h), one additional ball mill (5600 kW) and modifications to the conveyors and bins would be 50% of that required for installing a SABC circuit, or expanding the crushing circuit.

Typical product size distributions are shown below. The final product would contain more fines. Simulation studies have shown that the HPGR product has the potential of increasing the grinding capacity of the ball mills by 25%.

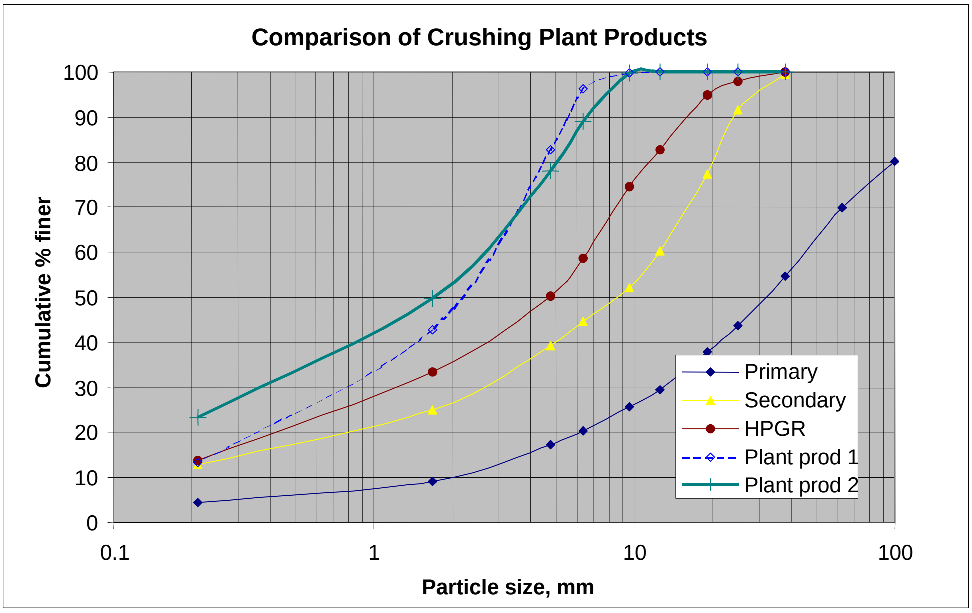


Figure 7.4 Crusher product size distributions (1-original plant product; 2- HPGR plant product).

3) The SC-HPGR-BM Alternative

A number of studies have been done by various groups in the last few years, on the HPGR as an alternative to SAG milling. The prime motive being to reduce capital and operating costs. Plant throughput rates of 3000 t/h are achievable with only 2 secondary crushers and two HPGRs.

Notably, the HPGR can be treated as part of the crushing circuit, so that the high availability of the grinding circuit is not coupled with preceding circuit, as in the case of SAG mills.

A case study done recently on a 50,000 tpd copper project showed:

Cost savings	- capital & installation	30% compared to a SABC circuit
	- operating	16%
	- power supply	10%
Benefits from	- faster start-up	14% of value of annual production
	- higher availability	6%

The overall savings and benefits in the 1st year are normally worth about a ½ year of copper production; and after 5 years, amount to over 2 years of copper production.

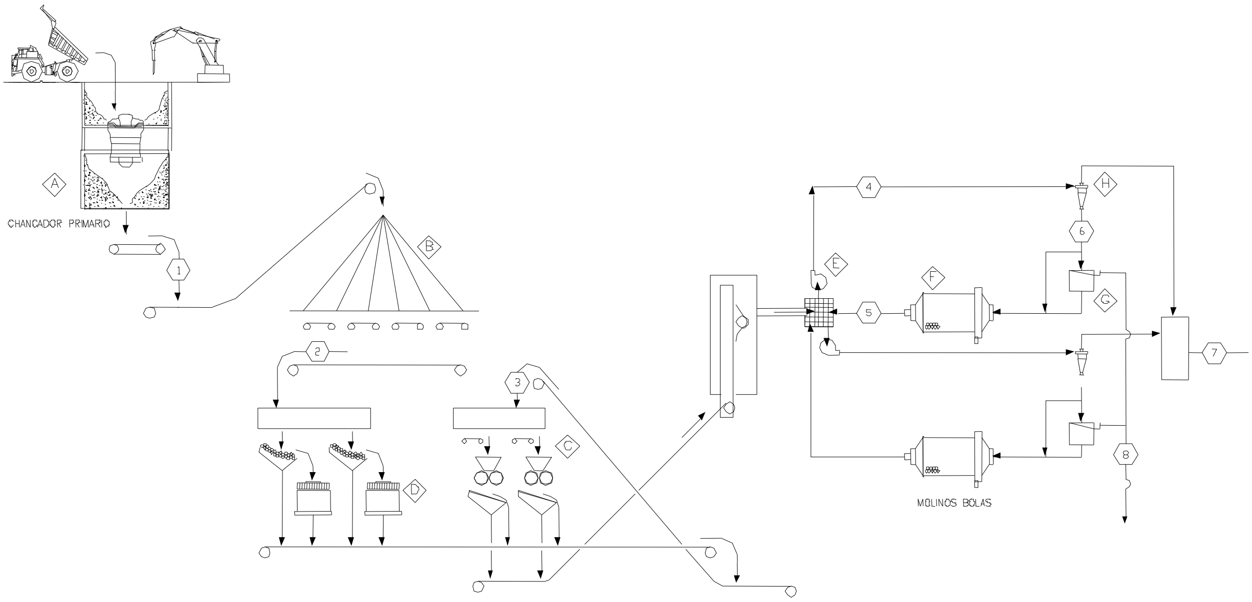


Figure 7.5 SC-HPGR-BM circuit.

The HPGRs can be started-up to achieve full production in two months. Furthermore, the crushing circuit with the HPGR can be de-coupled from the grinding circuit, so that each can commissioned separately, and operated at their respective availabilities. Overall production would then be determined by the availability of the ball mills, generally > 98%.

Other factors to be considered are the civil costs - a large HPGR weighs some 300 t, where as a fully loaded 38' SAG mill weighs some 2700 t. Also not included are production shortages after SAG mill liner change out, before the new liners are worn in. HPGRs offer a steady rate of throughout.

4) New developments.

The high availability offered by further developments in stud design and in side protection have opened the way to coupling the HPGR directly to the ball mill circuit – in a reverse closed-circuit configuration. In this configuration, full advantage can be taken of the fines produced by the HPGR.

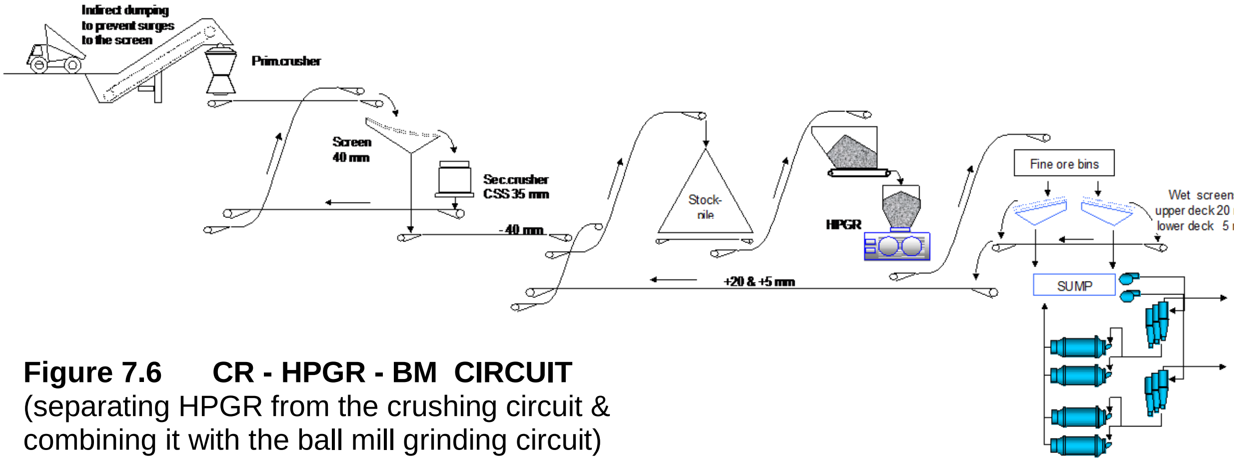


Figure 7.6 CR - HPGR - BM CIRCUIT
(separating HPGR from the crushing circuit & combining it with the ball mill grinding circuit)

Further advantages of this circuit are: only one stockpile is required; the feed to the HPGR can be limited to a size smaller than the gap (e.g., 40 mm); wet screening can be employed; the oversize can be de-watered in the stockpile; and the fresh feed and recycle product can be properly blended for the HPGR. Typical product size distributions are shown below. Note the screen product, P80 = 2.8 mm, can be fed directly to the sump of the ball mill circuit.

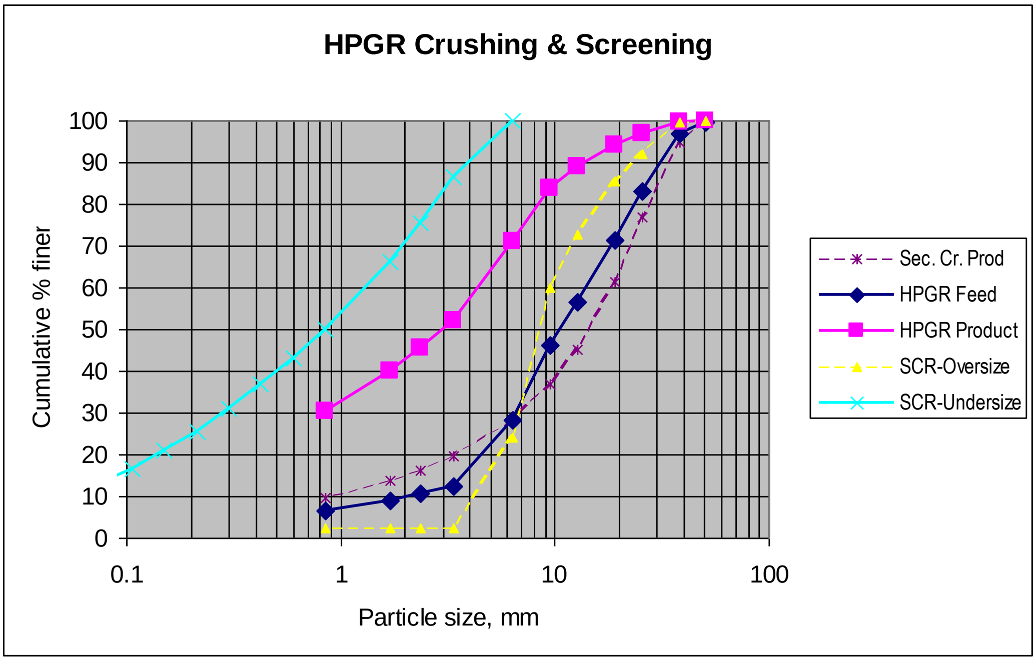


Figure 7.7

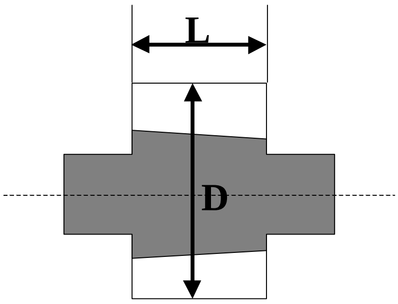
8. Testing

The purpose of testing is to develop the values for the key parameters:

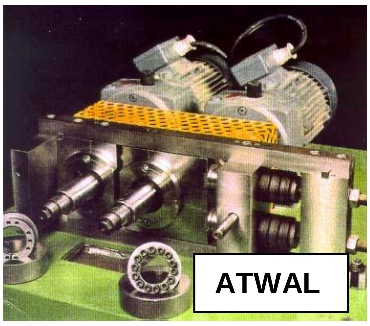
$$\dot{m} = \frac{M\ (t/h)}{D(m) * L(m) * u(m/s)},\quad \text{in units of}\quad ts/hm^3$$

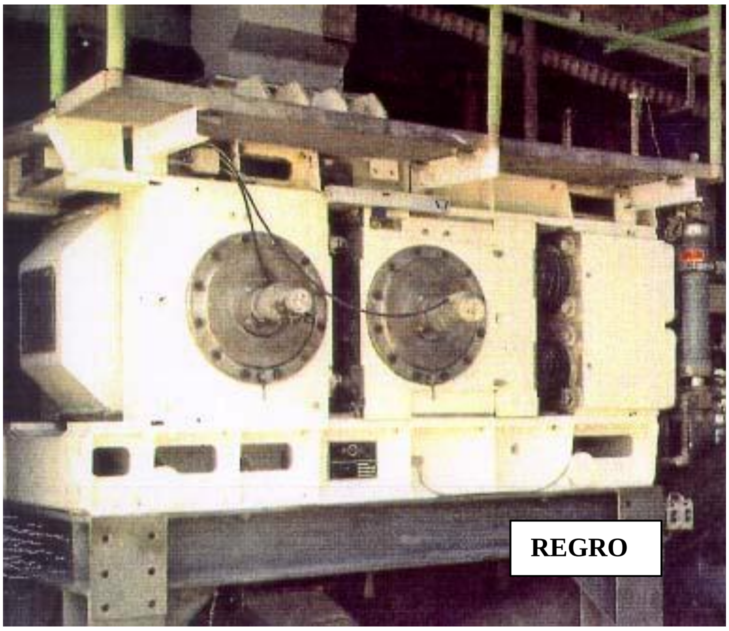
$$Fsp = \frac{F\ (kN)}{1000 * D(m) * L(m)},\quad \text{in units of}\quad N/mm^2$$

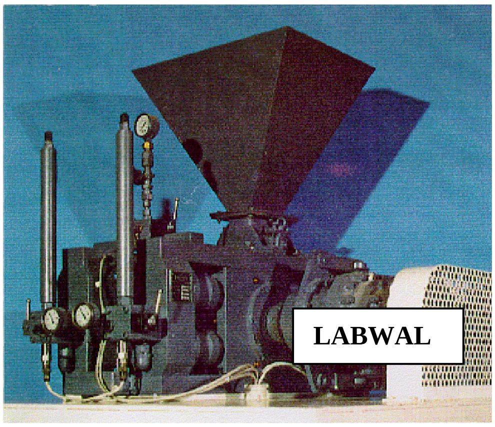
$$Wsp = \frac{P\ (kW)}{M\ (t/h)},\quad \text{in units of}\quad kWh/t$$



Testing is usually carried out on pilot size high pressure grinding rolls (REGRO). However, to determine effects of variations in properties of the feed, the testing may also be conducted on laboratory size rolls (LABWAL). Wear testing is done on smaller (ATWAL) rolls, which permit determining the weight loss due to wear.







Data of test units:

Diameter of rolls	: 0.71 m	Diameter of rolls	: 0.30 m
Width of rolls	: 0.21 m	Width of rolls	: 0.07 m
Speed of rolls	: 0.29 - 1.10 m/s	Speed of rolls	: 0.2 – 0.9 m/s
Top feed size	: 16 - 35 mm	Top feed size	: 8 - 12 mm

Testing should answer the following questions:

1. What grinding force is required to achieve the desired product fineness?
2. Is screening / recycling of the oversize required?
3. What are the effects of moisture – on the cake properties, throughput, & wear?
4. What specific throughput is achievable at the required grinding force & moisture? What is the recycle?
5. What specific energy input is required?

For field testing, larger units are available, e.g., **MAGRO**, with rolls 0.95 m diam x 0.35 m. The capacity of this unit is up to 100 t/h. This unit is equipped with all the latest wear protection.

MAGRO
0.95 m x 0.35 m
Capacity 80-100 tph

9. Scale & Sizing

Scale-up is an iterative process where careful consideration has to be given to the bearing and drive components.

The sizing of a HPGR begins with the selection of suitable roll dimensions to meet the throughput requirements. At this point, the L/D ratio becomes an important consideration, particularly with respect to the cost, performance and wear life of the rolls.

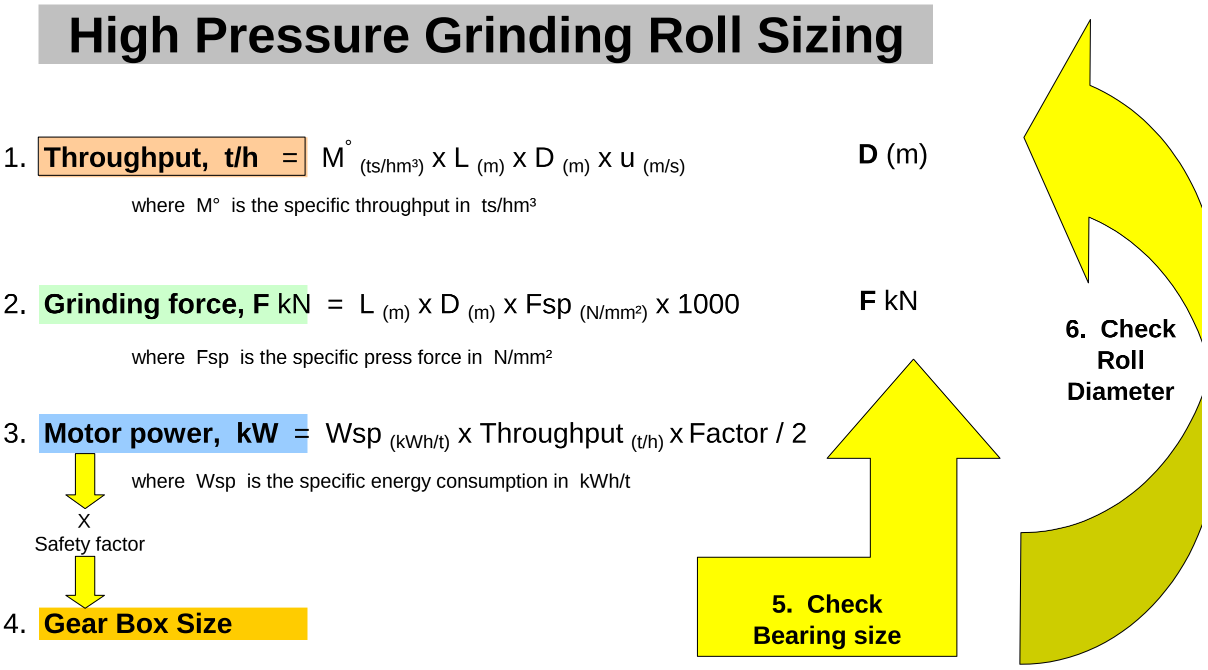
The next step is to select the appropriate model size to deliver the required grinding force. Models come in standard sizes, from 750 –20,000 kN. The specific press force is the calculated from the roll dimensions. The max. press force that can be applied to rolls equipped with studs is 4.0-4.5 N/mm². The change in product fineness above these pressures is minimal. Often lower press forces, 3.5 N/mm², are perfectly adequate.

The power required is determined from the throughput and specific energy consumption. Each roll is driven by a separate motor, so the power required for each motor is ½.

The next step is to determine the size of the gear box required to transmit the motor torque at a given roll speed. A large safety factor is applied to calculate the torque for the gear box. Finally the gear box is selected. Larger diameter rolls operate at lower speeds, and require larger gear boxes, however the wear life of the rolls is higher at lower speeds.

An iterative optimisation and check procedure follows to check whether the gear boxes can be bolted onto the size of rolls selected. Gear boxes can be shrink-fitted onto smaller roll shafts, however there is a risk of damaging the roll shafts during change out of the rolls.

Bearing lives for self-aligning bearings are usually > 40,000 hours.



High Pressure Grinding Roll Sizing

1. **Throughput, t/h** = $M^{\circ}_{(ts/hm^3)} \times L_{(m)} \times D_{(m)} \times u_{(m/s)}$ **D** (m)

   where M° is the specific throughput in ts/hm³

2. **Grinding force, F** kN = $L_{(m)} \times D_{(m)} \times Fsp_{(N/mm^2)} \times 1000$ **F** kN

   where Fsp is the specific press force in N/mm²

3. **Motor power, kW** = $Wsp_{(kWh/t)} \times Throughput_{(t/h)} \times Factor / 2$

   where Wsp is the specific energy consumption in kWh/t

   X
   Safety factor

4. **Gear Box Size**

Flow diagram of sizing procedure.

10. Conclusions

- The HPGR is now ready to deliver higher availabilities than SAG mill, and at lower capital, operating and installed costs.
- The problems with stud breakage, and wear on the edges/sides of the rolls have been overcome.
- The surface wear is predictable and manageable.
- Replacement of the roll units can be carried out in < 30 hours.
- There is no necessity of for dismantling the super-structure and feed chute. Nor is there a necessity for a heavy overhead crane to lift the rolls out of the unit.
- Acceptance of the technology has been achieved in the diamond and iron ore industries with over 40 units operating in these areas.
- The risk of applying this technology to harder, more abrasive copper and gold ores has - through intense development - been significantly reduced, opening the way to new and more cost effective approaches to circuit design, such as the coupling of the rolls directly to ball mill circuits.
- The rewards are widely recognised by engineering and mining companies alike - and are easily calculated.

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