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TECHNICAL AND COMMERCIAL BENEFITS OF GEARLESS MILL DRIVES FOR GRINDING APPLICATIONS

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Abstract

Gearless mill drives are a well established solution for grinding applications in the minerals and mining industries. The paper describes the functionality and technical features of such drive systems as well as their advantages compared to other drive solutions. Due to the variable speed operation the grinding process can be optimized for ores with varying grinding properties. This leads to significant optimization potential for the plant design as well as for its operation. Furthermore, energy and cost savings due to optimized operation, high system efficiency and high system availability are shown.

Introduction

In the past, for grinding applications often fixed speed drives have been used. Single-pinion and dual-pinion fixed-speed gear drives offer a relatively simple design. However, process flexibility and optimization can only be achieved with variable speed drives. Furthermore, mechanical problems and maintenance for gearboxes increase operating cost and reduce availability of ball and SAG mills.

Options for variable speed are DC motors, energy recovery systems for wound rotor motors and frequency converter drives. Improvements in power electronics technology and controls have resulted in variable frequency converters that offer high efficiency, high reliability and availability at competitive cost.

The first Gearless Mill Drive (GMD) with a power of 6.5 MW was installed 1969 in a cement milling process in the cement plant Le Havre in France. In the first few years, the GMD was only used in the cement industry. The GMD is also known as “wrap-around motor” or “ringmotor”. Almost 25 years later, the first GMD with 12.0 MW power and 13.0 rpm was installed in the minerals industry. Since then, numerous GMDs for ball mills and SAG mills have been installed in the minerals industry. The main advantages are that the GMD is adjustable in speed, and thus can fulfill the customer requirements with respect to flexibility and adjustability of the process, and that it does not need any gear box and ring gear and therefore eliminates mechanical wear and the related problems and maintenance. Furthermore, there are no real design limits, neither in the electrical part nor in the mechanical considerations, allowing scalability of the drive and design optimization towards specific customer requirements.

Overview of a GMD System

A GMD with a high power of up to 20 MW and more, as a result of today’s requirements for ball and SAG mills for the minerals industry, has of course a certain complexity. It should not anymore be regarded as a simple single drive. The GMD system includes not only the drive hardware including all auxiliary systems installed in an E-house, the drive control algorithm and all protection systems, but it also includes the control and supervision of the hydraulic and lubrication equipment for the mill bearings, the mechanical mill brake control and the visualization of all parts of the drive system.

Figure 1 shows a picture of a ringmotor used in copper concentrators. The poles of the rotor are directly mounted on the surface of the mill flange. Typically, the synchronous motors used in SAG mills have a power higher than 10 MW. Even ball mills have a power larger than 10 MW. For this reason, they have an important impact in energy consumption and in the operation of the power distribution system.

Figure 1. Picture of a typical GMD system for a SAG mill

Figure 2 presents the power circuit of a cycloconverter fed synchronous motor. The synchronous motor has one 3-phase winding in the stator. The current in each phase is controlled by a 12-pulse cycloconverter. The 12-pulse configuration is obtained by the wye-delta connection in the secondary winding of the power transformers and reduces the low frequency current harmonics in the load and at the input side of the converter. The motor field is excited by a separate controlled excitation system fed by its own excitation transformer.

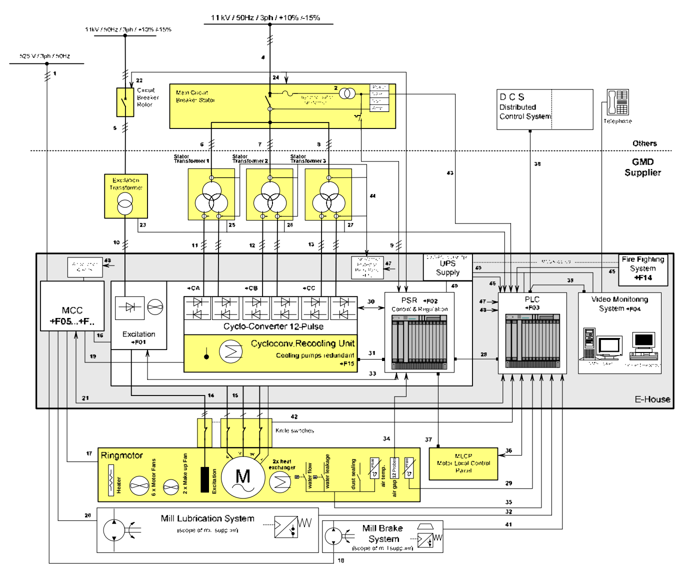

Figure 2. Overview of a typical GMD system and its components

Motor

The GMD is a drive system without any gear where the transmission of the torque between the motor and the mill is done through the magnetic field in the air gap between the motor stator and the motor rotor. The concept to drive the mill this way is relatively simple using the mill body as motor rotor and mounting the poles there. As a result the motor does not have a separate (motor) rotor and thus no separate (motor) bearings.

The number of poles is based on the required speed of the mill. The motor operates with typical frequencies from zero to about 6 Hz. In general, the bigger the mill diameter, the lower are the mill operating and critical speeds. Thus, for larger mills the number of poles will increase. As a result, the number of poles can vary from 48 to 72 poles (Fig. 3.) with typical mill speed requirements of about 10 rpm for larger SAG mills and about 15 rpm for smaller ball mills.

Figure 3. Pole mounting during installation of ringmotor

Cycloconverter

The cycloconverter (Fig. 4) belongs to the group of line-commutated static frequency converters, free from circulating current. The standard design for 12-pulse systems with higher power is fed from the mains via 3 transformers with one primary and two secondary windings.

Figure 4: Cycloconverter during testing

The basic design consists of a reversing, direct link, 3-phase 6-pulse bridge that has been used since years for DC drives. When higher power is required, the 12-pulse anti-parallel connection is used in order to attain higher motor voltages.

In line-commutated converters the output voltage is composed of time sections of the mains voltage wave. Each of the anti-parallel halves of the converter carries one half-wave of the output current, the voltage being able to assume either polarity (positive and negative) to form the sinusoidal motor voltage. Each phase of the stator winding of the synchronous motor is fed by its own frequency changer. Energy can be transferred in both directions directly without a DC link.

By means of phase-angle control this voltage can be continuously varied from zero to roughly the maximum phase-to-phase AC voltage, both in positive and negative polarity.

The reactive power of commutation required for the current transfer between the individual legs of each bridge is obtained from the power system. Only one of the anti-parallel bridges is in operation at a time, so that circulating currents are entirely excluded. When the current reverses, i.e. when the current commutates to the anti-parallel bridge, a short dead time is observed before the firing of the anti-parallel bridge will be released.

Operating Principle of Cycloconverters and its Implications

Two different modes of operation are used to control the entire speed range (i.e. frequency range) of the drive, sinusoidal operation (Fig. 5.) and trapezoidal operation (Fig. 6.). The sinusoidal operation ranges from the starting point up to the drive operational range. In this range, the output has a constant torque capability with varying power. The network power factor in this mode is from about 0.2 up to 0.8. This mode will be used in the lower speed range. To improve the mains power factor the trapezoidal mode is implemented in the upper speed range, where the cycloconverter also has to supply higher voltages. This mode also utilizes the static converters more effectively with respect to the voltage. In the trapezoidal mode a cycloconverter is operated at its firing limits for as long as possible over one cycle of the machine frequency. Since there is no star connection between the machine and the cycloconverter, the machine voltages still retain their sinusoidal shape. In this range, the output has a constant power capability with varying torque. It is operating in the field weakening range. The slope gradient of the trapezoidal characteristic does have a certain limit. The network power factor in this mode is about 0.84.

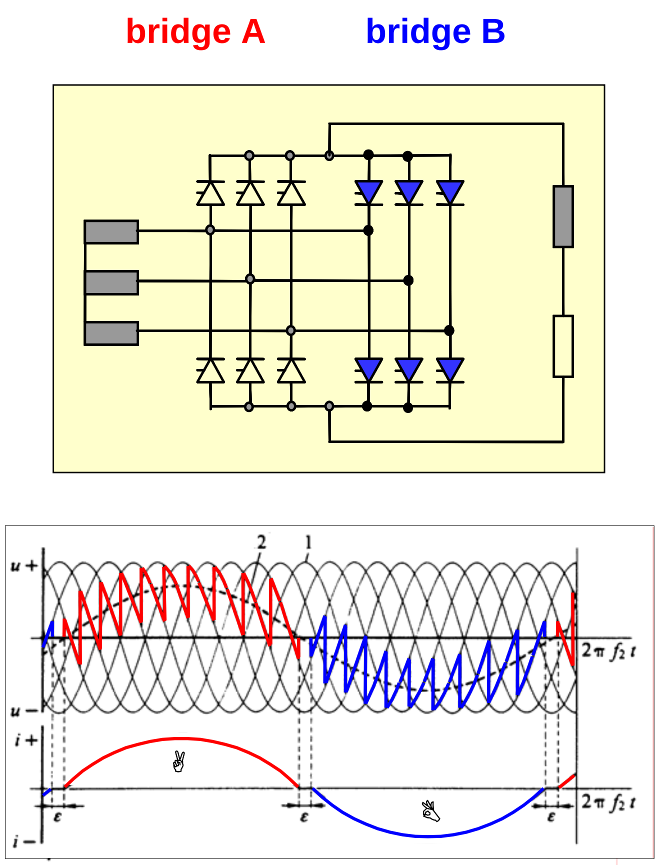

Figure 5. Sinusoidal operation

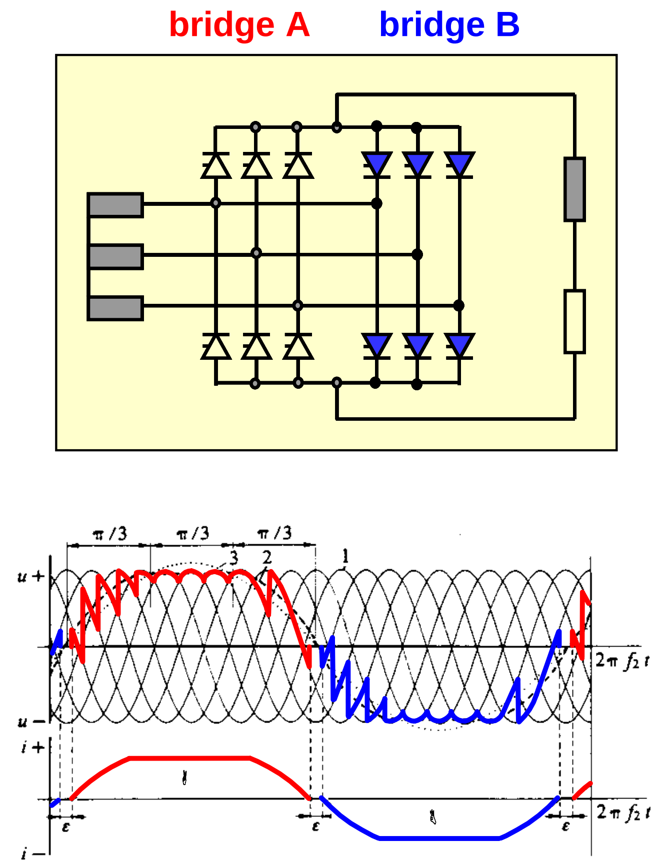

Figure 6. Trapezoidal operation

Since the output frequency of the cycloconverter is derived from the main frequency, it must be lower than the system frequency. In practice the output frequency can be continuously varied from zero to about 50 percent of the system frequency. For GMD applications the operational output frequency is typically from 0.3 Hz up to about 6 Hz (Fig. 7).

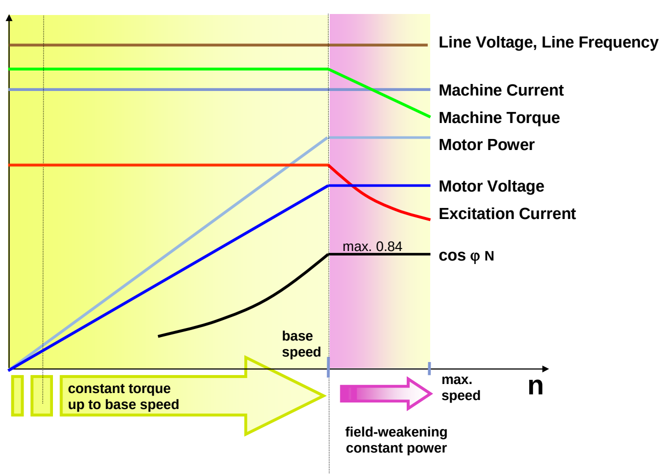

Figure 7. Operating range

Drive System Selection

When a drive system is selected for grinding applications, a large number of items need to be checked and many questions must be answered. Depending on the mill size and type, the mill can be driven by several configurations of drive systems. The main options are single low speed motors connected to a pinion driving a ring gear, two low speed motors connected to two pinions and driving a ring gear, or a gearless motor mounted directly onto the mill. In addition, a gearbox can be used to reduce the speed of a high speed motor. This gearbox is then placed between the high speed motor(s) and pinion(s) and the low speed shaft driving the ring gear. Thus, there is the decision between gearless drives and drives using a gear, and, if gear driven, between single and dual pinion configurations. Furthermore, a decision between fixed speed and variable speed drives must been taken. This selection process is of course plant specific and may be biased by customer preferences or company guidelines.

Several factors such as process, mechanical, electrical and cost considerations must be taken into account in the drive system evaluation. Choosing the correct factors is not easy. However, a proper evaluation and the right selection of the drive system are important for the plant design and has a high impact on future plant operation.

When determining the mill size and the drive type the required process power needs to be calculated based on design process specific energy (kWh/t), plant size (t/d) and total milling process power. The required process power is divided into circuits and numbers of mills within a circuit, followed by the selection of the mill sizes to fulfill the requirements. The optimal drive type can only be selected after determining the mill size, the need for variable speed and the characteristics of the electrical system of the plant.

Comparison of Drives Systems for Grinding Applications

The question what drive system is optimal for SAG and ball mills is project specific and depends on the plant layout and the design of the grinding circuit. When drives systems are compared the main criteria are operating characteristics (fixed speed or variable speed, starting behavior, interaction with network, harmonic distortion), maintenance aspects (reliability, wearing parts, downtime) and cost issues (capital expenditure, power factor and drive efficiency impacting energy cost, maintenance). In addition, drive systems show differences in other design and operational issues such as inching and creeping, load sharing (if dual pinion drives are used), frozen charge protection and space requirement.

Fixed Speed Drives

The use of squirrel cage induction motors is limited to small single pinion drives primarily due to the high inrush current of the motor when starting direct on line. Thus, the main fixed speed drives for SAG and ball mills are slip ring motors (also called wound rotor induction motor) and synchronous motors.

Slip Ring Motors

Slip ring motors are high speed fixed speed drives (typically 6 or 8 pole motors) that are usually used for smaller mills, but sometimes for larger mills as well. They offer a low capital expenditure solution compared with other drive systems. These motors are started with a starting resistor (oil starters with stepping resistors or liquid starters). Based on the resistor characteristics a relatively smooth start is possible. This drive system is rather robust against voltage dips. However, the power factor is typically not very high and gets even lower at part load conditions. Thus, often power factor compensation is installed individually for each slip ring motor. Furthermore, a separate device is required for inching and creeping.

Dual high speed slip ring motors can be used to drive through gearboxes to dual pinions. Load sharing is inherently possible but not very accurate. This can lead to load swings between the two motors and result in accelerated gear wear. To overcome these conditions, a permanent slip resistor may be installed between the two rotors. This will improve the load share capability, but at the expense of the drive efficiency (up to 1.5 % reduction).

Theoretically, speed regulation can be done with the starting resistor but this is a very inefficient solution. The starting resistor has to be designed for this operation. The slip power is dissipated in the resistor resulting in rather low drive efficiency.

Synchronous Motors

Synchronous motors can be either high speed motors driving the pinion through a main gearbox (typically 6 or 8 pole motors) or low speed motors driving the pinion directly through an air clutch without main gearbox.

Air clutches are used extensively with single and dual pinion low speed drives using synchronous motors. Air clutches are installed between each motor and its associated pinion. The clutch allows the motor to be started uncoupled. With weak power systems, reduced voltage starting of the motors is possible, and on dual pinion drives each motor can be started separately, thereby reducing the impact on the power system. Once the motors are synchronized, the mill is accelerated using the air clutches.

But as the mills grew in size, the clutches often became a big problem themselves. The newer clutches used for mill drives use a larger diameter than those in use two decades ago and thus have a lower torque density than the smaller diameter ones formerly used. Good reliability calls for maintenance of the drive. The clutch should be blown out weekly. Furthermore, the flexible coupling where the air enters the motor shaft deserves special attention and the necessary control systems for protecting the clutch such as pressure switches and slip detection need to be checked. As a result, service and maintenance is higher than for other drive systems and care should be taken to avoid excessive clutch wear (e.g. due to misalignment, during acceleration).

Synchronous motors have a high inrush starting current of 400 to 600 % of nominal current. The starting torque depends on the motor design and cannot be adjusted later on. These motors improve the network short circuit level and the power factor can be set from leading to lagging.

A thorough study is required to check voltage drop while starting both inside the plant facilities and out on the utility side of the plant substation. Even with a clutch synchronous motors may not be acceptable for some gear trains for ball mills because of the torque shock when the clutch is energized.

If the inrush current of 400 % or higher is too high and the requirement is for even less voltage drop during motor starting, a soft starter (e.g. reactor type) has been used to start the synchronous motor. This is only possible if the motor is clutched and started unloaded since the torque available is proportional to the square of the voltage and the clutch will be required to accelerate the mill. With this type of drive arrangement, the acceleration time will be controlled by the ramp control used in the soft starter. Since this drive depends on the clutch to accelerate the mill, it may not be acceptable for some of the pinion gear trains used for ball mills.

Synchronous motors for dual pinion applications have shown problems with torque oscillations. Therefore, special load sharing devices (Quadramatic) were developed. This functionality of course makes the drive system much more complex and expensive. This system has a special winding built into the quadrature axis of the motor rotors to allow load sharing and compensating for gear run-out.

After the clutches lock up, the load share between the two motors is monitored, and any error is adjusted by applying current to the quadrature axis winding in the motor rotors. If this error exceeds a pre-determined amount, an automatic clutch pulsing system comes into play and brings the two rotors closer to exact load sharing. The regulator controlling the quadrature axis current then brings the two motors into load sharing.

Variable Speed Drives

Slip Energy Recovery Drives. These drive systems use slip ring motors and are started similarly using starting resistors, thereby limiting the inrush current. To adjust the speed the slip resistance needs to be changed accordingly. This can be achieved by inserting resistance in the rotor circuit and dissipating this energy into the starting resistors. As mentioned before this solution is very inefficient. So rather than using the starting resistor, the slip energy is converted to direct current, inverted to the frequency of the power system feeding the motor, and then fed back into the power system through a step-up transformer. The switch-over to the slip energy recovery system can be done anywhere between 50 and 100 % of nominal speed. The speed range is smaller than of frequency converter drives, frozen charge protection is not possible and a separate inching drive is required. In reducing the speed of the slip ring motor, the slip energy recovery equipment will generate frequencies at multiples of 6 times the slip frequency, depending on the number of pulses built into the equipment. Because of these excitation frequencies there is a high probability that certain speeds in the operating range of the mill (possible resonance frequencies) will need to be blocked and it is not possible to operate within this particular speed range.

The main reason in the past for using slip energy recovery drives was capital expenditure. However, the use of these drive systems has very much decreased during the last decade. First of all, frequency converters have become more and more cost effective. Operational limitations and significant higher maintenance compared with frequency converter drives together with a diminishing difference in equipment cost have made this solution rather unattractive. As a consequence, most large drive manufacturers have stopped the production of slip energy recovery drive systems.

LCI Drives. Load commutated inverter (LCI) drives can be used with high speed and low speed motors. However, it needs to be pointed out that LCI drives are high speed drives in nature and therefore their use for low speed grinding applications has been limited. Continuous operation at low speeds (below 10 % speed) is not advisable because there is insufficient back EMF to commutate the inverter and thus the bridge is force commutated in this speed range, resulting in high torque pulsations. Often these pulsations are not acceptable and a separate inching device is needed.

Voltage Source Inverter Drives. Voltage source inverter drives can be used with induction motors as well as with synchronous motors. The lowest capital expenditure is given by a combination of voltage source inverter, squirrel cage induction motor and gearbox. However, this comes together with reduced efficiency and higher maintenance costs. When using low speed synchronous motors the gearbox can be eliminated.

These drives do not generate significant torque pulsations, show a very smooth starting behavior and are well suited for weak networks. The generation of harmonics is typically the lowest of all variable speed drives. Furthermore, the power factor to the network is high. If an “active front end” is included, then the drive system can operate at unity or leading power factor to the network. Inching and creeping does not need additional equipment. Other required operational features such as reversible operation and frozen charge protection are available as well.

Cycloconverter Drives. Besides using cycloconverter drives for gearless mill drives they can also be applied to geared drives both single and dual pinion, using low speed synchronous motors. However, for these configurations, since the output frequency is less than 50 % of line frequency, the motor will have a fewer number of poles in order to run at pinion speed. Basically, the technical features of the cycloconverter remain the same for both geared and gearless operation. However, in this configuration the system efficiency is reduced and maintenance is higher due to the ring gear.

Gearless Mill Drives. Cycloconverter drives are low frequency drives and have been the drive of choice for gearless mill drives where the motors operate at frequencies between zero and 6 Hz. Basically, voltage source inverter drives could be used for gearless mill drives too. However, drive control at low frequencies as well as space and cost considerations today still favor cycloconverter drives.

Because of the low frequency at which these motors operate the core losses only comprise approximately 10 % of the total motor losses, leaving the stator and rotor copper losses as the prime source of motor losses. This leads to a remarkably high motor efficiency. The elimination of any gears increases not only the efficiency, it also reduces the quantity of components and the related maintenance.

Gearless mill drives do not show significant torque pulsations, allow reversible operation, have integrated frozen charge protection, can run at very low speeds (for inching and creeping) and enable accurate positioning. For proper operation, a power factor compensation and harmonic filter system is installed. This is usually realized centrally and controls both power factor and harmonic distortion for the whole plant.

Capital expenditure for gearless mill drives is typically higher than for other drive systems. However, energy savings due to higher efficiency and reduced maintenance costs usually lead to smaller life cycle cost compared with other drive system solutions for SAG and ball mills.

Drive Comparison. In the following table the main criteria for selecting drive systems are given. This comparison is rather general. For specific projects process requirements, equipment cost, system efficiency and the related energy savings as well as maintenance aspects and the related costs need to be evaluated in detail.

The efficiency of the ring gear and the gearbox depends also on other factors, e.g. alignment, and can be significantly lower than the assumed values used for the comparison.

Table 1: Brief comparison of drive systems for SAG and ball mills

	Fixed Speed	Variable Speed	Ring Gear	Gearbox	Additional Inching Drive	Maintenance	Starting Behavior	Total System Efficiency (%)
Slip-ring motor	×		×	×	×	– –	o	93
Synchronous motor								
(low speed)	×		×		×	–	– –	95
(high speed)	×		×	×	×	– –	– –	93
LCI drives								
(low speed motor)		×	×		(×)	o	++	93
(high speed motor)		×	×	×	(×)	–	++	91
Cycloconverter drives (low speed motor)		×	×			o	++	93
Slip energy recovery drives		×	×	×	×	– –	o	91
Voltage source inverter drives								
(low speed motor)		×	×			o	++	93
(high speed motor)		×	×	×		–	++	91
GMD		×				++	++	95

Variable Speed Operation

For SAG mills the need for variable speed depends on a number of factors. With variable speed drives the operator (or the automation system) can rapidly react to changes in ore characteristics. These variations can be caused by different ore hardness or by a different feed size distribution. Soft and/or fine ore can result in a low total charge leading to liner damage and accelerated ball and liner wear. This condition can be corrected by increasing the circuit feed-rate only when downstream conditions permit such changes. Otherwise it must be corrected by reducing the speed of the mill to force the balls to impinge on the charge and not the liners. When grinding out a SAG mill, variable speed is valuable for the same reasons. Variable speed drives also provide the advantage of slow starts (stops) of the mill and, at least for some systems, inching of the mill.

For ball mill circuits, variable speed is valuable when circuit feed-rate control is required downstream. Without downstream constraints, ball mills are often operated with a maximum ball charge and a fixed speed. However, fixed speed operation of the ball mill limits the flexibility of the plant operation. Therefore, variable speed drives have shown to be advantageous for ball mills as well because this additional degree of freedom allows process optimization and helps to avoid operational limitations for the future.

AG and ball mill circuits are usually designed such that the circuit capacity is limited by the ball mill over most of the range of ore hardness expected from the ore body. Most variations are compensated by the variable speed drive of the SAG mill. In some cases, the ore may be so variable that the speed (or power) range of the SAG mill cannot compensate for an extremely hard component. This results in a need to reduce the power (or speed) of the ball mill to avoid over-grinding and negative affects for downstream processes.

It should be noted that mine planning, ore blending and blasting practices play an important role in the design of milling circuits. Modern plant designs recognize that feed characteristic control is not perfect and that variable speed SAG mills are necessary for any successful operation. In nearly all cases, regardless of the SAG mill diameter, variable speed is not an issue for evaluation and is accepted as the standard design. On the other hand, the drive evaluation for ball mills not always leads to the requirement for variable speed operation because in some cases the higher costs cannot be justified based on process considerations.

Two decades ago variable speed for SAG and ball mills was often considered as not needed. Today variable speed drives for SAG mills and partly also for ball mills are commonly used to optimize the grinding process.

However, the question for the optimal drive system still leads to discussions during the design phase of the grinding circuit. Many different aspects need to be taken into account but more and more the role of drive systems in the process optimization is considered. It is clear that without variable speed drives the possibilities for process optimization are very restricted.

The Antamina plant, situated in northern Peru at an altitude of 4300 m, mainly produces Copper and Zinc concentrate. The grinding circuit consists of one SAG mill and three ball mills with a huge total grinding power of more than 50 MW for an average design throughput of 70'000 t/d. It was one of the first plants in the world where both SAG and ball mills are powered by gearless mill drives. As a consequence, the speed of all mills is adjustable, which allows the operators to react to the different ore grades in order to get the best results in terms of milling efficiency. Furthermore, the total power requirement of the plant is above 100 MW operating on a rather weak network at the end of a long overhead line. This illustrates the capability of GMDs to successfully operate under such conditions.

Since the Antamina installation in 1999, several other similar plants have been equipped with GMDs for SAG and ball mills and are successfully operating. This documents the industry trend of incorporating variable speed drives in the whole grinding process to keep plant operation as flexible as possible.

Energy and Cost Savings

Process optimization can lead to a much more efficient use of grinding power and thus to significant energy savings. Furthermore, significant energy savings can be achieved with drive systems that have high efficiency.

Efficiency

The overall efficiency of a drive system takes into account all individual losses, such as for:

- Converter transformer
- Excitation transformer
- Cycloconverter

- Excitation converter
- Motor ventilation
- E-house air conditioning
- Motor copper losses
- Motor excitation
- Motor core and stray load losses

The overall efficiency for the complete GMD system depends on the size of the motor and the winding configuration and is typically around 95 % or above. No other variable speed drive system for SAG and ball mills achieves this high efficiency. Assuming energy cost in the range of 3 to 6 cents per kWh and an availability of the plant of 93 %, power savings of 1 kW result in cost savings of 250 to 500 $ per year. For a SAG mill with 15 MW of power a difference of 2 % in drive system efficiency leads to cost savings of 75 to 150 k$ per year. With a GMD system efficiency gains of 2 % and more compared with other drive systems can easily be achieved. Assuming a discount rate of 10 % the net present value of these energy savings (based on a 2 % efficiency gain) are in the range of 500 to 1400 k$ depending on the lifetime of the project.

Maintenance

Beside the cost savings related to energy savings additional cost savings can be achieved with reduced maintenance. GMD systems show excellent low speed characteristics without the need for any speed encoder. Cycloconverters are ideally suited for low speed applications and deliver precise and strong torque control during start up and during cascading of the material. The drive control has modes for inching and creeping. This allows fast, easy and accurate positioning of the mill and thus reduces the maintenance time needed for changing liners.

Service and maintenance for a drive system is mainly needed because there are parts that have wear such as gearboxes, bearings and carbon brushes or may get dirty or clogged such as heat exchanger tubes or air filters. These components need to be checked and replaced before the functionality cannot be guaranteed anymore, the behavior is degraded too much or the replacement would require an unplanned shutdown. It is clear that the maintenance work increases with the number of wearing components.

In case of component failures spare parts are needed on site to reduce downtime of the plant. However, proper design, operation of the equipment within safe limits and the use of supervision systems eliminate the risk of severe failures as far as possible.

Often routine maintenance of drive systems can be done during normal planned mill outages. However, the maintenance work that needs to be done for bearings, ring gears, gearboxes and other wearing parts leads to higher maintenance costs, tends to increase shutdown times and thus reduces system availability.

GMD systems have only very few wearing parts, i.e. the brushes and the greaseless motor dust sealing, and therefore need relative little service and maintenance. This ultimately results in very high availability of GMD systems and lower maintenance costs compared with other drive systems.

Space

Plant layout is a factor for evaluation when comparing geared and gearless drives. Obviously, the footprint for gearless, single pinion and dual pinion drives is different. Single pinion drives require the least amount of space, but only marginally less than gearless drives. Dual pinion drives have the maximum space requirement. In a single SAG mill circuit with two ball mills, the differences are generally small. However, for multiple line plants, the differences can be significant and require careful evaluation.

Additional Selection Criteria / Benefits for Plant Operation

Alignment

Today, the maximum power capacity per pinion is less than 10 MW. This could only be increased by improving the design of the ring gear set, such as ring gear hardness, face width or center distance. The reliability of ring gear sets is higher today than it has been in the past; however quality can very widely among them. Ring gears and gearboxes for high power and high torque are still a major source for downtimes caused by drive systems. Although component failures are not very frequent, problems with ring gears and gearboxes usually result in increased maintenance. Proper alignment and regular service are crucial for operation. Especially for dual pinion drive system the alignment needs to be addressed with the necessary care. Although sophisticated methods such as infrared alignment techniques help the user to make the proper adjustments dual pinion driven ring gears still require much experience to align.

The correct alignment of a drive train is critical to good performance of an installation. It is important to check the alignment regularly because foundations can settle and an initially correct alignment can move significantly during the first few months of operation. Misalignment between motor and pinion is a major reason for wear in a clutch. However, the drive train not only has to be aligned statically but it also must be checked dynamically when running with a loaded mill. Sometimes it has been proposed to continuously monitor the pinion tooth mesh with infrared to detect the development of a meshing error and to avoid excessive clutch and gear wear.

A major cause for concern in alignment occurs with a mill designed for operation in both directions of rotation. With a single pinion drive, the location of the pinion is such that the pinion tooth is lifting the girth gear and the pinion therefore presses down onto its bearings. If the rotation is reversed, the pinion tooth is now pushing down on the girth gear and the pinion is pushing upwards on its bearings. As a result, the pinion will lift upwards by the amount of clearance designed into the pinion bearings. This can be enough to increase wear in the clutch. Also by reversing rotation, the axial centerline of the mill will shift as the center of gravity of the charge moves from one side of center to the other. This problem also occurs with dual pinion drives where one pinion moves up whichever rotation is selected. The solution is to set the alignment at the mid point of the bearing clearance, which reduces the error by half and brings the alignment error to a more acceptable level.

With gearless mill drives, which are reversible by nature, the axial center line of the mill will move towards the center of gravity of the charge. The air gap between rotor and stator varies when the mill is starting to turn and the charge is being lifted prior to cascading. This has an impact on the unilateral magnetic pull between rotor and stator and must be considered in the design of the motor stator frame. However, the air gap of a GMD is rather large. Depending on the mill size it is in the range of 15 to 20 mm. Therefore, the system is not sensitive to small misalignments between the stator and the rotor, and special alignment procedures are not required.

Frozen Charge

When a mill comes to rest there is a tendency for the charge in the mill to settle and harden into a solid or semi-solid mass which is known as a locked or frozen charge. If an attempt is made to start the mill in this condition, there is a great risk of carrying the charge through to high angles (90 to 180º) at which point the charge will break away from the shell and crash across the mill with potentially destructive results for the mill and its bearings.

Frozen charge protection is a function that is realized inside the drive control software to detect frozen charges stuck in the mill shell. After the mill starts, the software calculates the angle of the mill. At a certain angle the charge inside the mill should start to cascade. This is recognized by the system because the actual current (torque) decreases when the material is cascading. If this decrease does not take place, then the system evaluates this behavior as a result of a frozen charge and trips the drive.

Inching, Creeping and Positioning

Inching or creeping is often used to avoid the occurrence of frozen charges, ensuring that the charge is loose and able to cascade. Furthermore, creeping is done to avoid or overcome mill deformation or high rotor unbalance e.g. due to uneven temperature and load distribution after an unplanned shutdown where a charged mill remained stationary for a long period of time.

Inching is used to position the mill for maintenance work such as liner changes. For this task the mill should accurately stop at the desired position and rotate at rather low speeds.

Many methods have been proposed to inch fixed speed drives and to check for a frozen charge but these usually lead to significant clutch wear and none of them is fully reliable.

If the mill operates with a variable speed drive, then the drive can be used for both inching and detection of a frozen charge.

It should be noted that if the motor is connected to the drive train during inching, then high pressure lift pumps must be installed at the motor bearings because the inching speed will be too low for the bearings to maintain an oil film. Also if the motor is used for inching electrically, then care must be taken to ensure that the time taken for inching is within the thermal capacity of the motor, unless forced air ventilation is used.

Load Sharing

When dual pinion drives are used then care must be taken that the load is shared between the two drives. Drives with frequency converters usually can address this issue with the drive control. One drive acts as master and the other as slave. With this master-slave-configuration torque and speed of the two drives are coordinated and a proper load sharing is achieved.

For fixed speed motors and slip energy recovery drives load sharing depends on the motor characteristics or requires additional equipment. Typically, slip ring motors will share the load on average within about 5 % and can use a common starting resistor. Gear run-out can give rise to load swings between the two motors during a revolution, which can lead to accelerated gear wear. Also motor characteristics may not match perfectly, which can cause an offset in load share between the two motors. To overcome these conditions, a permanent slip resistor may be installed between the two rotors. This will improve the load share capability, but it will be at the expense of the drive efficiency, which will be reduced by up to 1.5 %.

Synchronous motors for dual pinion applications have shown problems with torque oscillations. Therefore, special load sharing devices (Quadramatic) were developed. This functionality of course makes the drive system much more complex and expensive.

Supervision

GMD systems offer much information not only about the status of the drive system but about the mill as well. Dedicated supervision systems can help and guide the operator using the GMD system by providing the necessary information about the GMD and its sub-systems and to support service and maintenance of the drive. In addition, the values measured, recorded and collected by supervision systems give valuable input to analyze the status and the condition of the drive system and its components and therefore to detect potential problems and abnormal behavior in an early stage.

The main visualization system of a GMD is based on the signals available from the drive controller and the signals from auxiliary systems available through the PLC. The PLC is used to control the lubrication system, the brake system and the motor auxiliary system, to handle alarms and events and to communicate with the drive controller and the DCS. The visualization system, a dedicated HMI for the GMD, runs on a PC and is located in the E-house of the GMD. With this software trends can be viewed, alarm and event lists can be checked, active interlocks can be viewed, fault, warning and status messages can be checked and all sub-systems of a GMD can be monitored. These tools are valuable sources of information and can be integrated into the service and maintenance work. Potential problems can be detected and analyzed in an early stage and therefore unplanned shutdowns and downtime can be avoided.

Network Voltage Problems

Variable speed drives are able to operate at reduced voltage and the goal of any drive system is to stay on line as long as possible. Only if the power is lost for a longer period of time or if the situation is dangerous for the converter the drive systems are switched off.

A UPS is used to keep the drive control system alive, thereby allowing immediate restart after a power failure. The drive system can actively support network in case of voltage dips by reducing the power drawn from the network and thus at least not further contributing to the collapse of the network. GMD systems are mainly used for grinding applications and often operate in weak networks. They have such dedicated control features implemented that allow special operation philosophies that are beneficial especially for weak networks. When the voltage falls statically below a threshold value then speed and torque are gradually decreased. As a result, the drive will slow down and consequently the power taken out of the network will decrease as well. Therefore, this drive behavior is helping the network to allow a fast recovery. A warning signal will be provided to the process operator in order to adapt the feed if necessary for the process. In case the line voltage recovers then the reduced torque will ramp up to its set value again.

Summary

The functionality and technical features of gearless mill drive systems as well as their advantages compared to other drive solutions has been shown. Due to their technical advantages gearless mill drives are the primary choice for many grinding applications in the minerals and mining industries, especially for large SAG and ball mills. Due to the variable speed operation the grinding process can be optimized for ores with varying grinding properties. This leads to significant optimization potential for the plant design as well as for its operation. Furthermore, energy and cost savings due to optimized operation, high system efficiency, high system availability and reduced maintenance can be achieved.

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