MOLIENDA – ALTO CONSUMO DE ENERGÍA Y ALTOS REQUERIMIENTOS DE MANTENCIÓN, CÓMO SUPERAR LOS DESAFÍOS MEDIANTE EL USO DE CONVERTIDORES DE FRECUENCIA

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RESUMEN

La molienda es una parte destacada en el proceso de obtención de mineral.

La selección de soluciones de accionamiento para el molino tiene un impacto directo sobre el rendimiento, la flexibilidad de la operación, eficiencia total, confiabilidad y la vida útil de los equipos.

Con el aumento de tamaño de los molinos accionados mediante motores perimetrales, se ha incrementado la necesidad de contar con procesos optimizados de partida y funcionamiento suaves y controlados, así como también de una mayor eficiencia.

Las soluciones de accionamiento de velocidad variable para molinos con motor perimetral de piñón simple o doble ofrecen ventajas destacadas en comparación con accionamientos convencionales debido a sus características específicas de aplicación.

Existen soluciones con motores de baja velocidad, así como motores de alta velocidad para una amplia gama de configuraciones posibles para molinos accionados mediante motores perimetrales. Se puede obtener una alta disponibilidad de la molienda en general mediante una operación armónica del accionamiento tanto en los aspectos mecánicos como eléctricos.

Los esfuerzos mecánicos se reducen de manera drástica mediante partidas suaves y un control de torque rápido y preciso, lo cual minimiza el desgaste del motor perimetral y de los piñones, aumentando así el ciclo de vida total.

La limitación de torque y otras protecciones disponibles en el convertidor de frecuencia, así como sistemas para detectar cargas empaquetadas protegen el molino durante la operación de partida.

Características disponibles en el accionamiento tales como creeping, posicionamiento automático y contragiro controlado permiten mejorar el trabajo de mantención y reducir las paradas.

MILLING - ENERGY INTENSIVE AND HIGH MAINTENANCE,OVERCOMING THE CHALLENGES USING FREQUENCY CONVERTERS

ABSTRACT

The grinding process is a significant part of the ore winning process.

Selection of the drive solution for the mill has a direct impact on performance, flexibility of operation, total efficiency, reliability and the ageing of the system.

As the size of mills driven by ring-gear has increased, the requirements for soft, controlled starting and operation, optimized process control and increased efficiency have become more demanding.

Variable speed drive solutions dedicated to single or dual pinion ring-geared mills offer significant advantages over conventional drives due to their application-specific features.

Solutions with low speed motors as well as high speed motors cover all possible configurations available for ring geared mills. High availability of the overall mill system is achieved by the mechanical and electrical network-friendly operation of the drive.

Mechanical stresses are dramatically reduced by soft starting and fast, precise torque control, minimizing wear on ring-gear and pinions and therefore increasing the whole life cycle.

Torque limitation and other protections available on the frequency converter as well as frozen charge detection protect the mill during starting and operation.

Maintenance work is improved and the shut down shortened by the features available in the drive such as creeping, automatic positioning, as well as controlled roll-back.

INTRODUCTION

There are many possible electrical solutions to drive a mill, depending on the mill configuration and power requirement. It can be said that the mill configuration is defined by the maximal transmittable torque to the mill as shown in Figure 1.

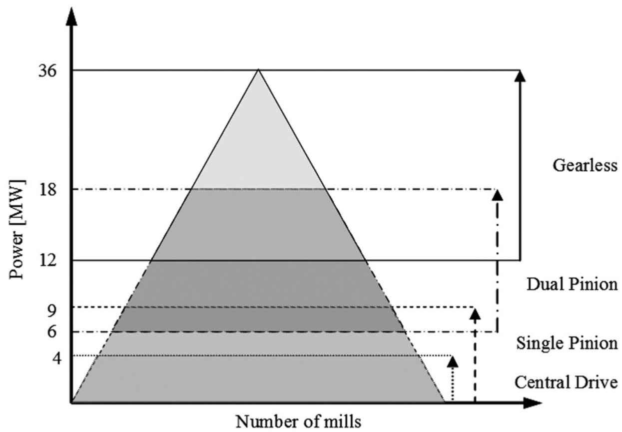

Figure 1: Possible mechanical mill configurations

The methods of powering the different mill configurations however can be different depending on the drive technology used and the process requirement. (Table 1)

The main differentiation is between the fixed speed and variable speed solutions as shown in the Figure 2.

Among the variable speed solution we can divide the drives into 3 main topologies:

- Cycloconverter
- Current Source Inverter
- Voltage Source Inverter.

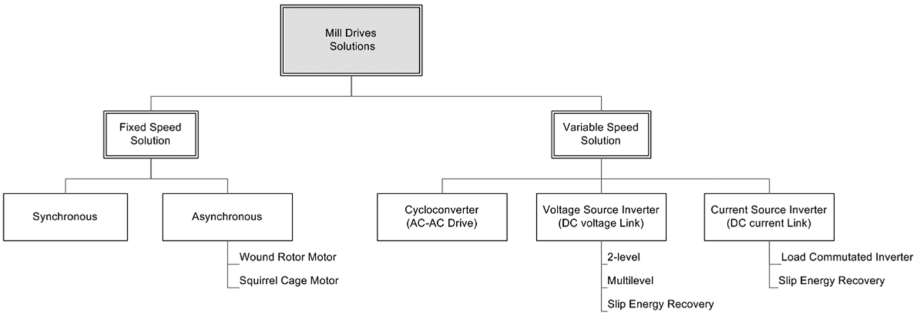

Figure 2: Drive classifications

The selection of the driven equipment is dominated by market demand, specifically by the capital expenditure of the available technology and the process requirements.

If we concentrate on the single and dual pinion configurations, we can see that these two configurations can be driven by low speed motors connected directly to the pinions driving the ring gear or by high speed motors that require a reducer between the pinions and the motors.

Fixed speed drives, with wound rotor motors or synchronous machines, were the common way of turning mills. Even if these are the simplest and the lowest capital cost solutions, they do not allow any flexibility in the operation of the mill and produce high stress on the network and mechanical equipment during the starting phase.

Nowadays, the frequency converter technology has taken over the industry. The volume of installed converter solutions increases every day. The evolution from fixed speed to variable speed brings additional advantages for the mechanical equipment, the electrical network and from the operation and maintenance point of view.

Presently SAG mills are mainly driven with variable speed drives, allowing the operator to react easily to the changes in ore characteristic and throughput.

Even if Ball mills traditionally did not need this feature if no feed-rate control was required downstream, nowadays frequency converter provide benefits, beside variable speed, that improve the Ball mill operation. These benefits will be explained later.

This paper will give a short overlook on the possible converter solutions. The focus will be on the multilevel voltage source inverter topology, because nowadays it is the most common solution in the industry due to its versatility and performance. The paper will present the advantages and possibilities that this kind of solution offers for the geared mills.

Table 1: Possible electrical mill configurations

		Motor Type	Motor Speed			Driving Equipment
			750 - 1500 rpm with Reducer	160 - 215 rpm without Reducer	9 - 15 rpm without Pinion	
Single Pinion	Fixed Speed	Wound rotor	x			Liquid, resistor starter
		Induction	x			DOL with air clutch
		Synchronous	x	x		DOL with air clutch
	Variable Speed	Wound rotor	x			SER
		Induction	x			VSI, CSI
		Synchronous	x			VSI, CSI, LCI
		Synchronous		x		VSI, LCI, CCV
		Permanent Magnet	x			VSI

Dual Pinion	Fixed Speed	Wound rotor	x			Liquid, resistor starter
		Synchronous	x	x		Quadramatic
	Variable Speed	Wound rotor	x			SER
		Induction	x			VSI
		Synchronous	x			VSI, LCI
		Synchronous		x		VSI, LCI, CCV
Gearless	Variable Speed	Synchronous			x	CCV

DOL: Direct On Line
SER: Slip Energy Recovery
VSI: Voltage Source Inverter
CSI:Current Source Inverter
LCI:Load Commutated Inverter
CCV:Cycloconverter

CONVERTER SOLUTIONS

In the not-too-distant past, variable speed solutions were limited and expensive. About 30 years ago a small number of drives were converter driven; most installed motors were fixed speed. Eighty percent of the variable speed solutions were accomplished with DC drives and the rest were based on the slip energy recovery system with a wound rotor motor or AC drives. Faster and more accurate controllers, the improvement in the power electronic components and the extensive reductions in costs and dimensions of the hardware have revolutionized drive process control methods. The efficient and reliable technology of AC drives has overtaken the DC solutions which have practically disappeared from the market. The selection of the type of drive supplying the mill is already a challenge due to the variety of possible solutions and the consideration and evaluation of advantages and disadvantages of each single solution in the initial costs and lifetime cost makes this even more difficult.

The high power required to turn a mill means medium voltage drives are the optimal solution.

There are different kinds of converter topology available on the market, from the cyclo converter and load commutated inverter mainly used nowadays for feeding big synchronous motors, to the more modern and state of the art voltage source inverter.

Slip Energy Recovery Converter

One type of Slip Energy Recovery converter (SER) consists of a three-phase diode rectifier bridge, which operates at slip-frequency and feeds rectified slip-power to a smoothing reactor and a line commutated inverter back to the AC supply network. Other topologies are available, for example, using a voltage source inverter with an active element on both sides. The speed of the motor is controlled by adjusting the rotor voltage. It requires a wound rotor induction motor with slip rings. The motor is controlled similarly to a wound rotor motor with different rotor resistances. Instead of wasting that energy in the resistor, the SER feeds the energy back to the supply network. In contrast to other drives, the SER is always regenerative and is varies the rotor losses of the motor, depending on the required speed. The power of the SER is therefore small; it needs to be dimensioned only for the power losses of the rotor.

Table 2: Advantages and disadvantages of Slip Energy Recovery

ADVANTAGES	DISADVANTAGES
Cost effective because VSD only needs to be dimensioned for the feedback power (as long as motor not operated at lower speed)	Only for WRIM motors
	Low Power factor defined by the WRIM motor and not constant over entire speed range
High total efficiency	Requires starter
Inherent by-pass	High maintenance
Inherent 4 quadrant operation	Indicated for speed range of 80-100% of nominal speed. Not suitable for speed < 10% (creeping)

ADVANTAGES	DISADVANTAGES
Drive power small	Resonances with mechanics can be excited by the SER over the slip frequency
	Uni-directional motor operation

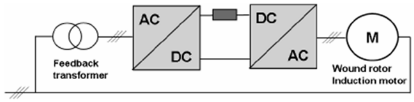

Figure 3: Example of Slip Energy Recovery converter topology.

Current Source Inverter

The Current Source Inverter (CSI) contains a controlled (line or self-commutated) rectifier on the line side, a DC link with a reactor, and a self-commutated inverter on the motor side which converts the direct current to an adjustable frequency three-phase current. The amplitude of the motor current is adjusted by the controlled rectifier, whereas the frequency and thus motor speed is operated by the inverter.

This converter is suitable for small single pinion mills due the low performance at low speed and high torque. In fact the majority (around 85 %) of the installed MV CSI drives are for high power fans, pumps, and compressors with quadratic torque characteristics.

Table 3: Advantages and disadvantages of the Current Source Inverter

ADVANTAGES	DISADVANTAGES
Motor friendly wave form	Poor power factor varying over the speed range
Inherent 4 quadrant operation	Limited dynamic performance compared to voltage source drives
Inverter fault current controlled by the DC reactor	Output capacitor filter (risk of resonances)
Bi-directional motor operation	torque control difficult especially at low speed
Suitable for synchronous and induction motors	Not suitable for speed < 10 % (creeping)

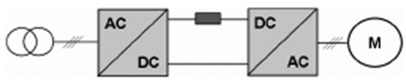

Figure 4: Current Source Inverter topology

Load Commutated Inverter

A Load Commutated Inverter (LCI) requires a Synchronous Motor and contains the line commutated thyristor rectifier which forms a fully controllable DC-current source in conjunction with the reactor in the DC link. The DC-link reactor smoothes the DC current and limits the dI/dt in the event of a fault. The load commutated thyristor inverter switches the DC current so as to produce a three-phase ac system of variable frequency for supplying the motor. The motor voltages commutate the inverter phase currents. At low speed, force commutation is required because of the lack of an electrical magnetic field on the motor.

This topology is used mainly to feed low speed synchronous motors for single and dual pinion mills.

Table 4: Advantages and disadvantages of a Load Commutated Inverter

ADVANTAGES	DISADVANTAGES
Inherent 4 quadrant operation	Poor power factor varying over the speed range
Robust, efficient and economic drive	Lower dynamic performance compared to voltage...

ADVANTAGES	DISADVANTAGES
	source drives
Inverter fault current controlled by the DC reactor	Force commutation between 0 -10 % speed -> high torque ripples during starting
Bi-directional motor operation	Not suitable for speed < 10 % (creeping)

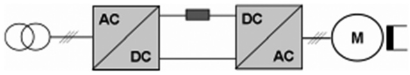

Figure 5: Load Commutated Inverter topology

Cycloconverters

Cycloconverters are network commutated converters (without intermediate DC circuit) usually fed from a supply network via transformers. The cycloconverter operates as a three-phase current source. Each motor phase has an AC- AC converter consisting of two anti-parallel thyristor bridges creating an AC stator voltage with variable amplitude and variable frequency. The cycloconverter output frequency is limited to approximately 40 % of the line frequency, making this drive suitable for low speed solutions.

Therefore this topology is mainly used for driving gearless mills requesting high torques at low frequency. It could be suitable for single and dual pinion mills, however nowadays the voltage source inverter provides more advantages and limited risks.

Table 5: Advantages and disadvantages of Cycloconverters

ADVANTAGES	DISADVANTAGES
Inherent 4 quadrant operation	Limitation on max output frequency (limited to 40 % of the line frequency)
Higher efficiency than other drives	
Excellent performance at low speeds	Power factor not constant over entire speed range
High stall and holding torque available	High harmonic contents -> filter required
High dynamic overload capacity	Network transients and faults are reflected directly on the motor side (short circuit)
Bi-directional motor operation	
Lower pole number for low speed solution	Torque limiting coupling required
Creeping speed and positioning available	
Frozen charge protection during starting available	

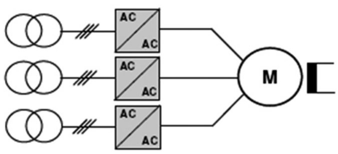

Figure 6:Cycloconverter topology

Voltage Source Inverter

The Voltage Source Inverter (VSI) consists of a rectifier which creates a constant DC voltage in the DC link and an inverter output unit. The capacitor bank in the dc link smoothes the DC voltage and supplies reactive power to the motor. The rectifier can be of a 2 quadrant type, built with a robust diode bridge or alternatively can be of a 4 quadrant type, built out of a controllable power semiconductor. It is however not required by a mill. The mills are typically single quadrant application. Some are designed for running in both directions.

The self-commutated inverter units use Gate Turn-Off Thyristor (GTOs), High Voltage Insulated Gate Bipolar Transistor (IGBTs) or Integrated Gate Commutated Thyristor

(IGCTs), with both two or higher level types are available. Voltage Source Inverters (VSI) are the most common topology today.
The simplest topology is the two-level source inverter.

This switches DC (+) to DC (-) voltage in the DC link creating the output phase voltage, which can be varied in amplitude and frequency. However, the output signal is highly distorted and the output voltage is limited to a maximum of approx. 2.3kV. This means higher currents and thus thicker cables.

The large dU/dt, created by the switching of only 2 levels of voltage, induces currents through the capacitive coupling of the cable shields, limiting the cable length. Furthermore, the harmonic current distortions generated are very high, heating up motors, not built for 2-level VSI operation.

To avoid all these issues multilevel voltage source inverters were developed, reducing the THD below 5 % even for low frequency. This 5 % is the magic number, because a machine is usually designed to thermally absorb the extra heating due to such a THD. A multilevel solution permits a higher motor voltage, reducing the size of the cables. With an appropriate output filter reflections and over voltages on the cables are prevented and the cable length is no longer limited.

Table 6: Advantages and disadvantages the Voltage Source Inverter

ADVANTAGES	DISADVANTAGES
Power factor above 0.95, no filter required	Fault current not controlled on motor side
Lower pole number for low speed solution	Transformer required
High dynamic performance for the torque control over full operation range	Higher capital cost than a direct converter
No relevant torque pulsation generated	Larger size than a direct converter
Creeping speed and positioning available	Cable length limitation
Frozen charge protection during starting available	Output voltage limitation
Suitable for synchronous and induction motors	
Bi-directional motor operation	
Network transients and faults are not reflected on the motor side	

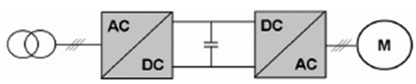

Figure 7: Voltage Source Inverter

The replacement of traditional Pulse Width Modulation control (PWM) with improved motor control method such as Direct Torque Control (DTC) drive technology in the mid 90s enabled the highest torque and speed performance available in AC drives. Control has a very fast dynamic response and it is smooth under all condition making DTC the best solution for running mills. The high performance and robustness of DTC is achieved because of its simplicity. The control of torque and speed are directly based on the electromagnetic state of the motor (flux and torque).

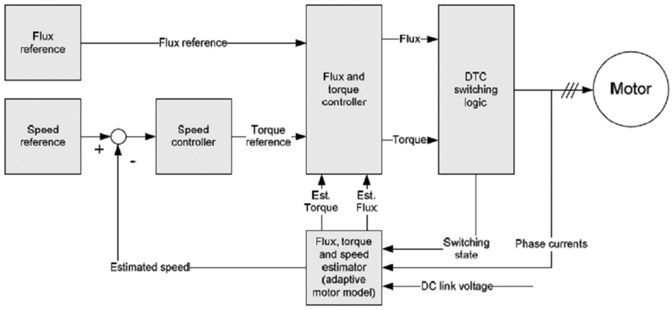

Figure 8: Block diagram of the DTC control

The DTC does not require any modulator as does PWM controls speeding up the response time in torque changes and allowing precise torque control. This is extremely important for dual pinion mills in order to be able to share the load of the two drive trains equally. The open loop control shown in Figure 8 is accurate enough to control the mill without a speed sensor even on a dual pinion solution, however for frozen charge protection and mill position an encoder is still required.

DRIVE CONFIGURATION FOR GEARED MILLS WITH VSI

Geared mills have two main different drive configurations; in case of a high speed solution, an AC induction motor, or a brushless synchronous motor for low speed solution. They are fed by a frequency converter connected via a transformer to the medium voltage distribution.

The freedom to select the voltage level for connection of the drive, due to the converter transformers can have a big impact on the design of the complete medium voltage distribution of the plant. Having the mill drive system connected to higher voltages, allows reduction in costs on voltage transformation, and reduces transmission of currents, and hence losses.

The High Speed Motor Solution

The high speed motor solution is simplest, from the electrical point of view, because it requires only a squirrel cage induction motor and does not need any excitation panel as per a low speed solution with a synchronous motor. The disadvantage however, is that to reach the required mill speed a gearbox is required. This increases the scope of mechanical equipment, space and maintenance required, decreases the reliability of the system due to the additional component and increases the overall costs.

The squirrel cage motor is the most common motor used in the industry. It is versatile, reliable and simple. The maintenance is reduced to a minimum. The motor is generally forced cooled; this allows running the motor at very low speed so that inching and creeping with the main drive can be achieved. Typically a 4 – 8 pole induction machine running at 30 – 60 Hz is used to turn the mill.

The Low Speed Motor Solution

In the low speed motor solution the gearbox is removed, increasing the efficiency of the complete system.

The motor, however, has to provide the complete torque required to turn the pinion, making it larger. Squirrel cage motors can usually not handle this high torque and therefore synchronous machines are used. Brushless synchronous motors are the most suitable solution for the mill. They have no wearing parts, therefore are almost maintenance free and the AC/ AC excitation power is kept small. The brushless exciter is a separate AC generator mounted on the motor shaft. The excitation control and the necessary protection are integrated in the drive.

In addition to their high torque capability, synchronous motors offer a wide field weakening range. This allows the design of motors with nominal frequency below the network frequency. The low speed solution motor, when used with the drive has a nominal frequency varying from 10 – 20Hz. This means a machine with 8 – 12 poles can be used instead of the big 30 – 40 pole machine required by a fixed speed solution having the same torque output.

The main benefits of the low speed motor solution with only 8 to 12 poles, beside the lower capital cost compared to the traditional low speed motors with 30 to 40 poles, is the compactness of the motor. Less weight, smaller dimensions and therefore easier shipment and installation create less demand in the foundation design.

OVERCOMING THE CHALLENGES

As the size of mills driven by ring-gear has increased, the network and the mechanical equipment are getting more and more sensitive to rough operation. The challenges to operate and protect the mill are getting bigger and require special attention. In addition the maintenance has to be optimized in order to keep shut downs and the loss of productivity to a minimum.

The main challenges this paper is focusing on are:

- Starting
- Load sharing for dual pinion mills
- Mill protection
- Operation: Increase throughput and save energy
- Reduce mechanical wear
- Reduce downtime for maintenance.

The inherent advantages that come with a frequency converter using voltage source inverter technology, combined with mill operation features and protections available in a dedicated controller has met the requirements of these demands.

Starting

One of the main challenges is to have a smooth start with low starting currents and low mechanical stresses especially for high power and dual pinion mills.

From the electrical point of view high inrush currents and low power factor create high stresses and voltage drops endangering the other consumer in the plant.

From the mechanical side the torque pulsation and peak torques generated by all types of fixed speed solution during starting ages the mechanical equipment.

With a voltage source inverter the start is not anymore a problem. The power factor is kept constant at 0.95 lagging under all conditions during starting and operation. Even if the non linear load generates harmonics, these are kept to a minimum thanks to the 12 and 24 pulse configurations. The drive can provide full torque from zero speed allowing the machine to start directly coupled to the mill without an air-clutch. This reduces capital and maintenance cost as well as mechanical wearing components.

The high dynamic performance and torque control over the operating range of a voltage source inverter, specially with DTC control, allows the mill controller to take care of the starting sequence by accelerating the mill to a minimum speed (usually approx. 10 % of nominal of speed) while the frozen charge protection is activated. It keeps this speed until it is confirmed that the material has started to cascade, before accelerating to the operational speed. The time frame for the starting is adjustable. Usually it takes less than one minute to bring the mill to operational speed. This allows a really smooth start without high torque steps.

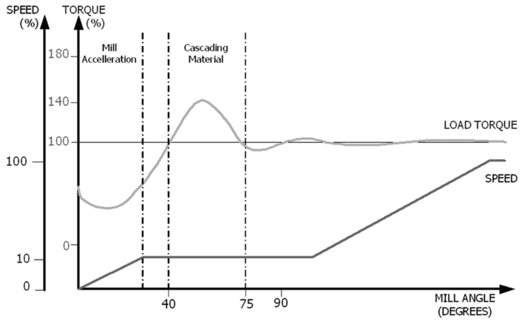

Figure 9: Starting sequence

Load Sharing for Dual Pinion Mills

In the case of a dual pinion mill, care must be taken that the load is shared equally between the two motors. Therefore a fast and active electronic control of the torque sharing is needed inside the voltage source inverter. The speed reference is sent from the process control to the master drive. The actual torque generated by the master drive is used as a reference for the follower drive. The fast DTC control, calculating the actual torque values every 25 µs, ensures an accurate and proper load sharing.

Mill Protection

Increases in mill sizes require a higher level of protection of the mill than is available from classic motor protection; such as torque limiting and stall protection; to mill specific protection, such as frozen charge protection. Thanks to the DC-link of the voltage source inverter the motor is also protected from the network transient and faults.

Torque control and limitation

Adaptive torque control and limitation, backlash control (also known as damping the gear run out) reduces mechanical stress and contributes to overall life cycle costs. The ring gear and the gearbox are protected from torque pulses by the fast and accurate drive control.

Frozen charge protection and remover

After a long standstill, the material inside the mill can be solidified and stuck to the mill shell. The detection of frozen charge is of significant importance in order to avoid major damage to the mill shell, bearings and liners. For loosening the solidified charge the Frozen Charge remover can be applied.

This function helps to break up the solidified charge and loosen it from the mill shell.

The mill is started at low speed and torque steps are applied to break the frozen load. As soon as the mill has reached the maximum safe angle (below the cascading angle of 40...60°), the mill will be stopped with controlled roll back. The same procedure can then be performed in the other mill rotating direction, if required and the mill is capable of being turned in both directions.

Operation: Increase Throughput and Save Energy

The inherent feature of a voltage source inverter is to be able to vary the speed of the mill to meet the process requirements. The system can rapidly react to changes in quantity or quality of the ore characteristics allowing the operator to adjust the speed accordingly. These variations can be caused by different ore hardness, type of granularity, or the content of other ores and non-soluble products, etc. or by a different feed size distribution. Even if variable speed during operation is not required, it gives the opportunity to tune the speed of the mill for optimal grinding and maximum throughput, without needing to change any mechanical components (e.g. pinions or ball charges) during starting of mine operation or over the years as the ore characteristics changes. If the mill is operating with partial load, the drive is capable adjusting the speed according to the fill level of the mill. This ability means the grinding throughput can be matched to the up- and down-stream process requirements without stopping the process and also energy is saved.

Fine tuning of the speed of a mill optimizes the process, leading to a much more efficient use of grinding power and thus to significant energy savings. It decreases the need to regrind the ore that does not reach the required particle size and therefore increases material recovery and lower the grinding media consumption and increases in the same time the productivity and efficiency of the flotation (in case of copper). Speed variation of the ball mill avoids over grinding and affecting down stream processes in cases the SAG mill cannot compensate ore variations.

When a ball mill is overloaded for whatever reason (hydro-cyclones short-circuited for example), the operator has the chance to increase the speed to the mill and reduce the mill load and keeps the process running. On mills without variable speed, when a mill is overloaded it has to be isolated and the ore feed to the SAG mill has to be reduced impacting the production. If the opposite occurs, and the mill is under loaded the speed can be decreased as described above.

In case of a short stoppage of the SAG mill just for checking something on the shell, drum, etc. the ball mills are not stopped, as would be the case for fixed solution, only the speed is reduced and as soon as the SAG mill is in operation again the process starts smoothly just by increasing the speed of the ball mills, avoiding production loss draining out the mill and sumps. This allows reducing the consumption of fresh water. Variable speed also allows a controlled clean out of the mill, and to drain the sump if the mill has to be stopped for a long period, permitting a faster restart.

Increasing the availability of the mill operation is also a factor that increases the mill throughput. A less network sensitive and relatively maintenance free drive such as the voltage source inverter with the possibility of a ride through functionality allows operation and starting with reduced supply voltage or to overcome voltage dips during operation requiring fewer restarts and achieving more grinding time.

Reduce Mechanical Wear

Another big challenge for the mill operation is to reduce the mechanical wear. This allows a longer life time of the liners, balls as well as pinion and gear. Improving the mechanical wear increases the availability of the mill besides reducing the costs of the consumable. Having the grinding loop designed for running the mill in both directions permits the use of them on both sides and increases the time between replacements, allowing more productivity. With a voltage source inverter this feature is available just by changing a parameter.

The availability of low operational speeds, besides optimizing the grinding quality depending on the ore characteristic and load, allows filling and emptying of the mills during any process interruption while still protecting the liners and minimizing their wear.

Beside liner protection and prolongation of their lifetime, permitting a higher throughput a special attention has to be taken to the drive train.

Ring gear, pinion and gearboxes (if any) are subject to backlash if the torque applied is not properly controlled. An accurate and fast torque control of the mill prevents backlash between the teeth of the pinion and the gear ring increasing the lifetime of the equipment.

Reduce Downtime for Maintenance

The possibility to perform maintenance work on the mill with the main drive allows shortening the down time. It does not require additional equipment and additional procedure and mechanical interlocks between the so called inching drive and the main drive.

Creeping speed can be set in the drive controller depending on the work that has to be performed. During the liner change procedure, the mill can be positioned either manually or automatically, based on mill angle or liner reference. When performing the automatic positioning the material inside the mill is considered. The controller will bring the mill in the selected position with the material in balance making the complete liner procedure faster and easier. The lower adjustable creeping speed allows for optimal visual inspection in the optimal time.

Additional features as controlled roll back permits to shorten the rocking of the mill allowing a faster stop.

Tools like remote diagnostics help the operator during maintenance or trouble shooting, by having system expert connected online and supporting them from any part of the world. This decreases down time and increase production time.

CONCLUSIONS

In conclusion, running a mill with a voltage source inverter provides many operational advantages, flexibility and protection to the mechanics besides being network friendly. As shown in the previous chapters the availability of different configurations as well as the operation and protection features suits all kinds of mills even if the initial capital costs look higher than a fixed speed solution. The versatility of the drive solution can provide a standardization of mill electrical equipment and rationalization of spare parts throughout the whole mine site. The challenges are mainly overcome by the use of this solution allowing less down time, less equipment wear optimal grinding and energy consumption and therefore more production, which is at the end the biggest goal that every mine site wants to achieve.

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