

**COPPER MOUNTAIN: OVERVIEW ON THE GRINDING MILLS AND THEIR DUAL PINION  
MILL DRIVES**

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## **COPPER MOUNTAIN: OVERVIEW ON THE GRINDING MILLS AND THEIR DUAL PINION MILL DRIVES**

### **ABSTRACT**

This paper will first give a short overview of the Copper Mountain project in British Columbia, which just has started commercial operation earlier this year. The grinding process with one 34' x 20' SAG mill and two 24' x 39.5' ball mills will be briefly discussed. All three mills are gear driven by a ring gear, dual pinion and two low speed synchronous motors. Copper Mountain has installed on all three mills, the new state-of-the art dual pinion mill drives. All the inherent operation and maintenance features of this drive technology will be discussed, as well as the advantage of having variable speed control also on the ball mills. The installation and commissioning of the mills and drives at Copper Mountain will be briefly reviewed. Finally the first field measurements on these low speed mill drives will be presented, with the main focus on the low mechanical stress impact of these mill drives on the pinion and ring gear, as well as the accuracy of the load sharing between the two motors.

### **KEYWORDS**

SAG mill, ball mill, ring gear, dual pinion, drive systems, variable speed

### **INTRODUCTION**

The project is located 15 km southwest of Princeton, British Columbia (BC), an established mining town. The initial exploration at Copper Mountain dates back to 1884. In 1923, Granby Consolidated Mining, Smelting and Power Company (Granby) acquired the property, built a milling facility in Allenby adjacent to Princeton and extracted 31.5 million tonnes of ore with a grade of 1.08% copper, primarily from underground excavations in, and below, what are now the Pit 1 and Pit 3 areas. Mining operations were suspended in 1957, partly due to low metal prices and partly due to transportation charges on the ore by the owners of the rail line. Newmont Mining Corporation of Canada (Newmont) purchased Granby's entire mining interest in the district and began mining the Ingerbelle deposit in 1972. In 1979, development of mineable reserves on the Copper Mountain side of the project commenced with the installation of a new primary crusher and conveyer system. Initial production on the Copper Mountain side was from Pit 2 with additional production from Pit 3 in 1983. Mining of Pit 2 ceased in 1985. In 1988 Cassiar Mining Corporation (later to become Princeton Mining Corp.) purchased Similco Mines Ltd. which owned the property. Mining production continued from Pits 3 and 1 until the mine closed down in late 1993 and stayed on a "care and maintenance" basis until copper prices improved in mid 1994. Mining concentrated in the Ingerbelle pit and low grade stockpiles in 1995 and was again closed at the end of 1995. A lack of low strip ratio reserves, rising production costs and necessary capital expenditures resulted in the mine closing down in November of 1996.

Copper Mountain Mining Corporation is a BC resource company that is developing the Copper Mountain Project located 15 km south of the town of Princeton in southern British Columbia. The Project is owned 75% by Copper Mountain Mining Corporation and 25% by Mitsubishi Materials Corporation. Copper Mountain Mining Corporation completed one of BC's largest drill exploration programs in 2007 and 2008 by drilling approximately 106,000 meters.

The goal of the program was to test and possibly expand the reported resources between the pits to identify a new merged pit – known as the “Super Pit” that would be bigger, wider and deeper gaining access to additional mineralization at greater depth. In 2009 an independent feasibility study was completed that confirmed the economic viability of bringing back into production a conventional open pit mine with a 35,000 tonnes per day mill. The mine with an estimated resource of 5 billion pounds of copper is designed to produce approximately 105 million pounds of copper concentrate per year (first 12 years) with gold and silver credits. A completely new concentrator has been built, which went into production in June 2011. The grinding circuit consists of a SAG mill and two ball mills, all dual pinion gear driven. Copper

Mountain has selected the state-of-the-art dual pinion mill drive systems, providing numerous advantageous features which were previously exclusively available on gearless mill drives.

## GRINDING CIRCUIT

The grinding circuit for the Copper Mountain project consists of one FLSmidth SAG mill and two FLSmidth ball mills.



Figure 1 - Overview grinding circuit

The Copper Mountain SAG mill is 10363 mm [34 feet] in diameter and 6096 mm [20 feet] long. It is a grate discharge mill with an inside diameter of 10363 mm [34 feet] and a grinding length of 5334 mm [17.5 feet]. The mill is driven by two 8,500 horsepower ABB motors.



Figure 2 - The 34' x 20' SAG mill

Table 1 includes the technical data for the Copper Mountain SAG mill.

Table 1 - general SAG mill data

Specification	Data
Mill size	10.363 M [34 feet] diameter by 6.096 M [20 feet] long
Mill type	Wet grinding, grate discharge
Mill drive motor size	17,000 HP
Mill drive motor type	Synchronous 200 RPM
Inside diameter	10,363 mm
Length	6,096 mm
Effective grinding length (EGL)	5,334 mm
Bearing type	Partial Journal, 120 degree bronze insert
Bearing size	2,950 mm diameter by 660 mm wide
Bearing material	Bronze
Bearing lubrication type	Hydrostatic dual pocket

Table 2 and 3 include the process and operating data for the Copper Mountain SAG mill.

Table 2 - general SAG mill circuit and ore data

Specification	Data
Operating circuit	Closed-circuit
Operating mill ball charge	15 percent by volume
Operating mill total charge	32 percent by volume
Mill speed	10.08 RPM (76 percent of critical speed average)
Ore specific gravity (sg)	2.77
Ore bulk density	1.64 tonnes/m <sup>3</sup>

Table 3 - SAG mill operating requirements

Specification	Data
Throughput rate (new feed)	1,585 dry mtpH (average)
Ore feed size F80	150,000 microns
Ore product size P80	2,200 microns
Downstream grinding stages	Yes

### The 24' x 39.5' Ball Mill

The Copper Mountain ball mills are 7315 mm [24 feet] in diameter and 12040 mm [39.5 feet] long. They are overflow discharge ball mills with inside diameters of 7315 mm [24 feet] and grinding lengths of 11887 mm [39 feet]. Each Ball mill is also driven by two 8,500 horsepower ABB motors.



Figure 3 - The 24' x 39.5' ball mill

Table 4, 5 and 6 include the technical data for the Copper Mountain ball mills.

Table 4 - general ball mill data

Specification	Data
Mill size	7.315 M [24 feet] diameter by 12.039 M [39.5 feet] long
Mill type	Wet grinding, overflow discharge
Mill drive motor size	17,000 HP
Mill drive motor type	Synchronous 200 RPM
Inside diameter	7,315 mm
Length	11,430 mm
Effective grinding length (EGL)	11,886 mm
Bearing type	Partial Journal, 120 degree bronze insert
Bearing size	3,200 mm diameter by 710 mm wide
Bearing material	Bronze
Bearing lubrication type	Hydrostatic dual pocket

Table 5 - general ball mill circuit and ore data

Specification	Data
Operating circuit	Closed-circuit
Operating mill ball charge	32 percent by volume
Operating mill total charge	32 percent by volume
Mill speed	11.89 RPM

	(76 percent of critical speed average)
Ore specific gravity (sg)	2.77
Ore bulk density	1.64 tonnes/m <sup>3</sup>

Table 6 – ball mill operating requirements

Specification	Data
Throughput rate (new feed)	795 dry mtph (average per mill)
Ore feed size F80	2,200 microns
Ore product size P80	150 microns
Recirculating Load design	350

### Special Design Considerations For Grinding Mills Driven By Dual Pinion Low Speed Drives

In the past, mills driven by a dual pinion drive option have utilized an air clutch not only to start the mill, but also to facilitate rough load sharing between the two pinions. Due to the unique starting capacity and accurate load sharing functionality inherent to the ABB dual pinion drives that are installed on the Copper Mountain mills only a torque limiting coupling is used in place of an air clutch. Since the load sharing is performed internally within the ABB drive itself rather than by pulsing air clutches to maintain even load sharing between the two motor and pinion drives a clutch is not required. Rather a torque limiting coupling is installed to safeguard against the remote possibility of a very large torque spike due to a short circuit on the motor terminals that could cause severe damage to the gear, pinions, bearings and mill. The coupling is set to release at a torque above the maximum expected operating torque but below the maximum rated torque of the ring gear and pinion. If the release torque is exceeded for any reason, the coupling will release and allow the motor shaft to spin independently of the pinion shaft thereby isolating the pinion from the torque spike.

The torque limiting coupling type installed at Copper Mountain is an adjustable mechanical type torque limiter that utilizes precision Belleville springs rather than viscous fluid or shear pins to transmit the torque from the motors to the pinion shafts. In the event the coupling releases there is no fluid to clean up or shear pins to replace. The Bellville spring modules are simply reset using a mallet once the coupling halves are rotated back to the proper alignment.

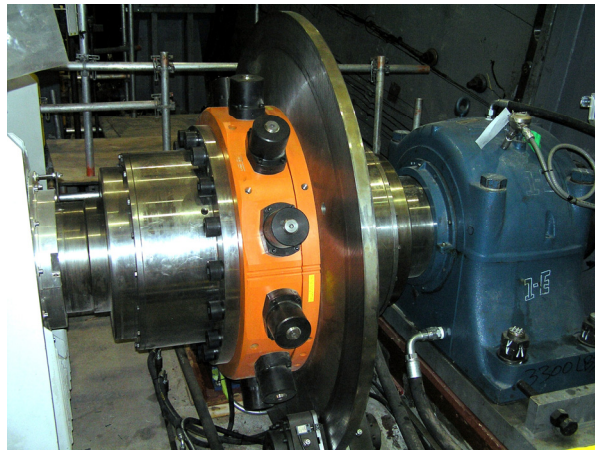


Figure 4 – Torque limiting coupling

Another design issue that must be considered with the ABB dual pinion mill drive is whether there is a need for a separate inching drive. Because the ABB drive is variable speed and is capable of turning the mill slowly and spotting the mill manually or even automatically for maintenance activities, the need for an inching drive may be eliminated. If the plant expects they will need slow turning capabilities for any

reason at a time when the main motors are not operable, then an inching drive is the best solution. Typically a dedicated inching drive will turn the mill at a speed of about 0.15rpm. In the case of Copper Mountain, the inching mode in the ABB drives are currently set to turn the SAG mill at about 10 % of rated speed and the ball mills at about 3% of rated speed (mill speed 0.40 rpm). Furthermore tests during the hot commissioning have shown that the drives can even operate in inching mode at as little as 1% rated speed (mill speed 0.10 rpm).

On a large dual pinion mill, using the ABB drive to rotate the mill for maintenance is an advantage over an inching drive, because the inching torque is transmitted by the dual drive system to the mill through both motors and both pinions simultaneously. When an inching drive is used, all of the inching torque is transmitted through only one of the two pinions, requiring a larger diameter pinion shaft and in turn larger pinion bearings.

It should be noted that for safety considerations on a mill without an inching drive, a brake should be included to serve as the braking function normally provided by the inching drive. The Copper Mountain mill drives were supplied with brake discs mounted on the torque limiting couplings, and dual brake calipers mounted on the foundation beneath the coupling. The brake discs are mounted on the pinion shaft side of the coupling to ensure the brake is able to function even after the release torque of the coupling has been realized.

## **DUAL PINION MILL DRIVES**

The SAG and the two ball mills are gear driven and Copper Mountain selected the sophisticated low speed dual pinion mill drives from ABB to drive these mills.

### **Brief History Sophisticated Dual Pinion Mill Drive Technologies**

About five years ago, ABB was already the market leader for Gearless Mill Drives (GMD). ABB had delivered several projects where the scope has been the GMD for the SAG mill, but was often not awarded to supply the gear driven ball mill motors. ABB then decided to enter also the market for the dual pinion mill drives. Initially ABB evaluated what was already available for gear driven mills. First of all it has to be noticed that there is the following important differentiation on the mills: either with or without a gearbox.

- With a gearbox: the motor is connected to the gearbox, which again is connected to the pinion and ring gear. The motor is a high speed motor, with a rated speed of typically around 1000 or 1200 rpm. Normally an asynchronous wound rotor induction motor with secondary starter was used. This configuration can often be found in concentrators located in South Africa, Europe and Australia.
- Without a gearbox: the motor is connected directly to the pinion and therefore a low speed motor is required with typically a rated speed of around 200 rpm. This used to be to a high pole (around 36 poles) synchronous motor. This configuration can often be found in North America.

For both solutions, the conventional dual pinion mill drive systems have several significant disadvantages. Therefore instead of just copying an existing and rather outdated technology, ABB's target was to have a superior, but still competitive, dual pinion mill drive system available for the market, with most of the exclusive features inherent to the GMD technology included. These unique inherent features of ABB's sophisticated dual pinion mill drives are:

- Mechanical soft starting
- Mechanical smoothness required
- Frozen charge detection
- Frozen charge remover
- Controlled roll back

- Inching, creeping
- Automatic positioning
- Dual pinion: very accurate load sharing
- Electrical soft starting
- Variable speed

ABB's solution for the high and low speed dual pinion mill drives is shown in Figure 5.

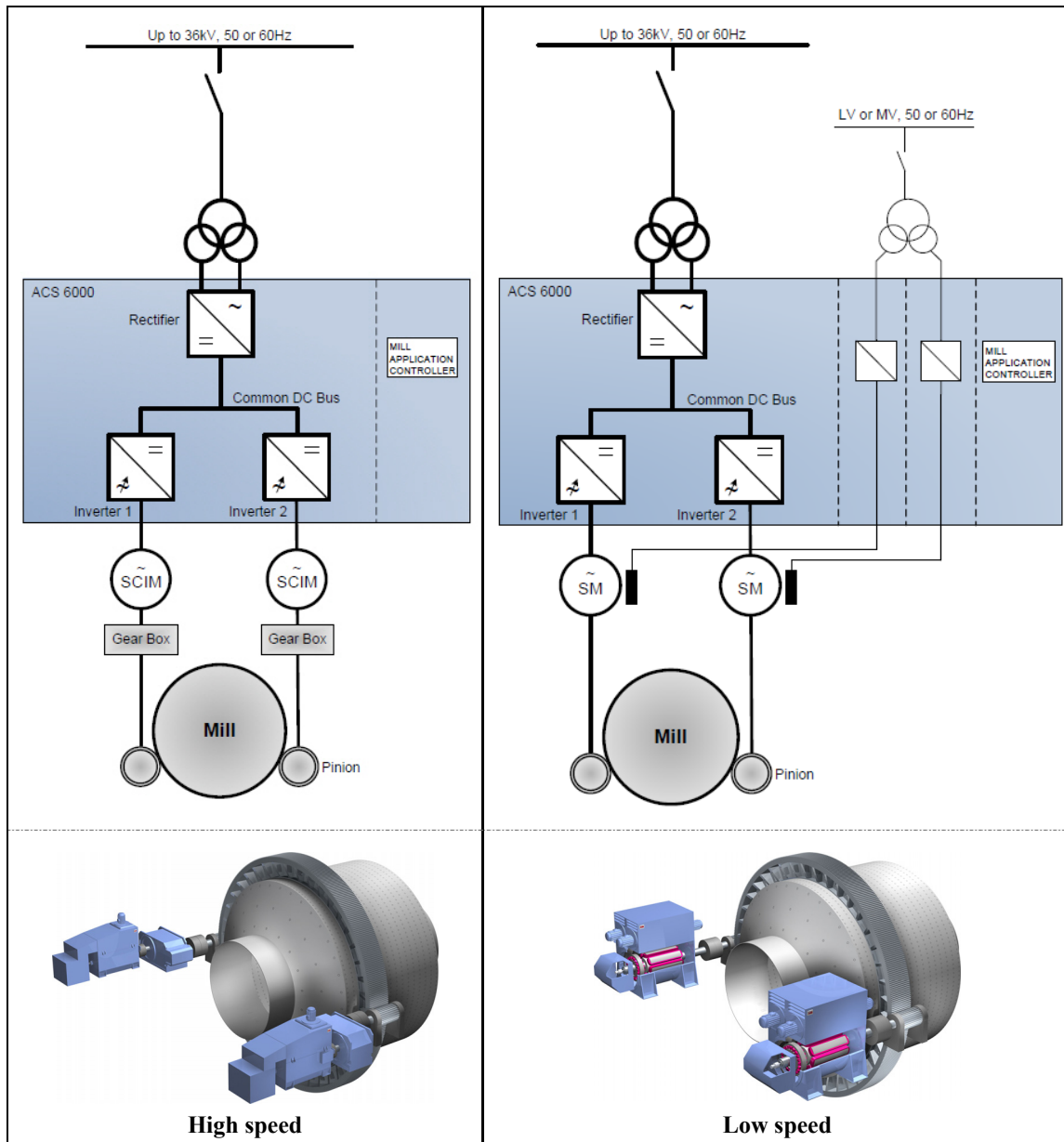


Figure 5 - Schematic overview low speed and high speed mill drive



A paper with detailed measurements taken on a 2 x 5 MW dual pinion high speed mill drives has been presented in another paper earlier this year (Rufli & van de Vijfeijken, 2011). The high speed solution requires asynchronous squirrel cage induction motors as where the low speed solution is realized with synchronous motors. Apart from this fact there is basically no difference in the drive technology between the two. For both solutions the ACS 6000 drive is used, which is not just a standard frequency converter or variable speed drive (VSD), but it is based upon ABB's unique direct torque control (DTC) technology. This technology is used in all of ABB's standard low voltage and medium voltage source inverters and it enables a fast and very accurate direct control of the three essential motor parameters: speed, flux and torque (refer to Figure 6).

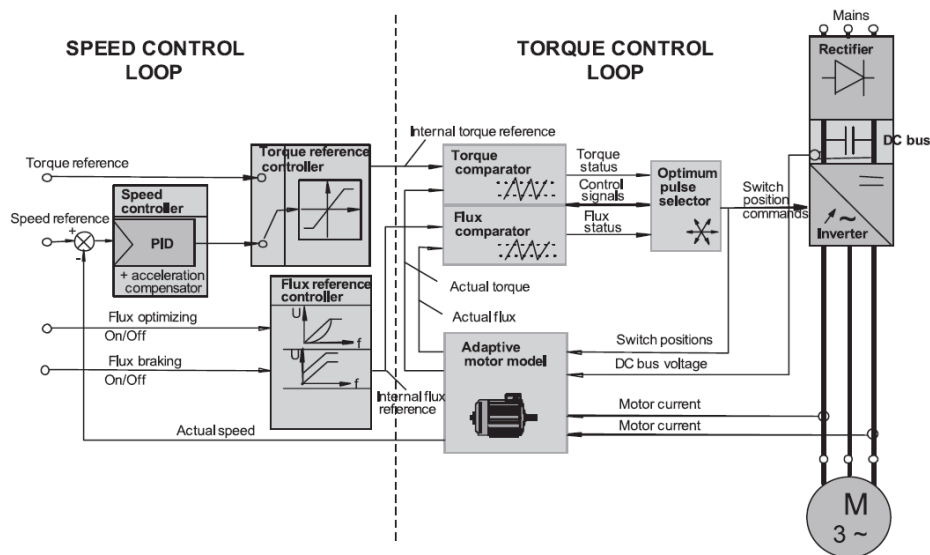


Figure 6 – Overview ABB's direct torque control technology

The DTC provides the basic technology to control the mill motors in the required fast and accurate manner. Furthermore ABB developed for the ACS 6000 a dedicated mill application controller and together with the superior DTC technology, it was possible to realize all the earlier described unique mill drive features.

### The Mill Drives Of Copper Mountain

The SAG and ball mills at Copper Mountain are the low speed version, i.e. the motors are connected directly to the pinion without a gearbox in between (the picture on the right hand side of Figure 5). Figure 7 shows one of the synchronous motors installed on Ball Mill 1.



Figure 7 – ABB synchronous motor on Ball Mill 1

The drive requirements for the Copper Mountain mills are as follows:

- Rated power: 2 x 6340 kW (2 x 8500 hp)
- SAG mill rated motor speed 204 rpm, max. motor speed 214 rpm
- Ball mill rated motor speed 195 rpm, max. motor speed 209 rpm
- Starting torque: 150% for 15 s
- Main voltage level where the drive system is connected: 25 kV
- Excitation power is provided by a 4.16 kV bus

As the power requirements for the SAG and ball mill drives are identical and the rated speeds are only varying slightly, with the ABB drive concept all the six motors have been manufactured basically identical. The only difference in each pair of motors for every mill is the location of the terminal boxes, as due to the plant layout the terminal boxes of two motors for each mill are located at the opposite side.

At the time of writing this paper, the mill drives at Copper Mountain had just been commissioned and the first measurements on these mill drives are presented in this paper to demonstrate the implementation of the earlier mentioned features.

#### Mechanical Soft Starting

The conventional low speed solution consists of two high pole (approx. 36) synchronous motors, which are brought first up to rated speed without load, because in the conventional configuration these motors can not develop the required high starting torque. Then the air clutches are engaged and within approximately 7 – 8 seconds the mill is brought up to full speed. Not much imagination is needed to understand that such a kick-start is quite stressful for the mechanical components on the drive train, such as the ring gear and the two pinions.

But also for the conventional high speed solution typically with wound rotor induction motors it has been shown (Hamilton et al, 2006) that several torque spikes occur during starting, potentially leading to problems on the mechanical components of the drive train. In addition for both solutions with and without a gearbox, it will be even more stressful when the alignment of the gear and pinion is not being perfect. With increased mill power ratings, the power and torque transfer per pinion increase also, leading to greater width of the teeth of pinions and ring gear (refer to Figure 8).

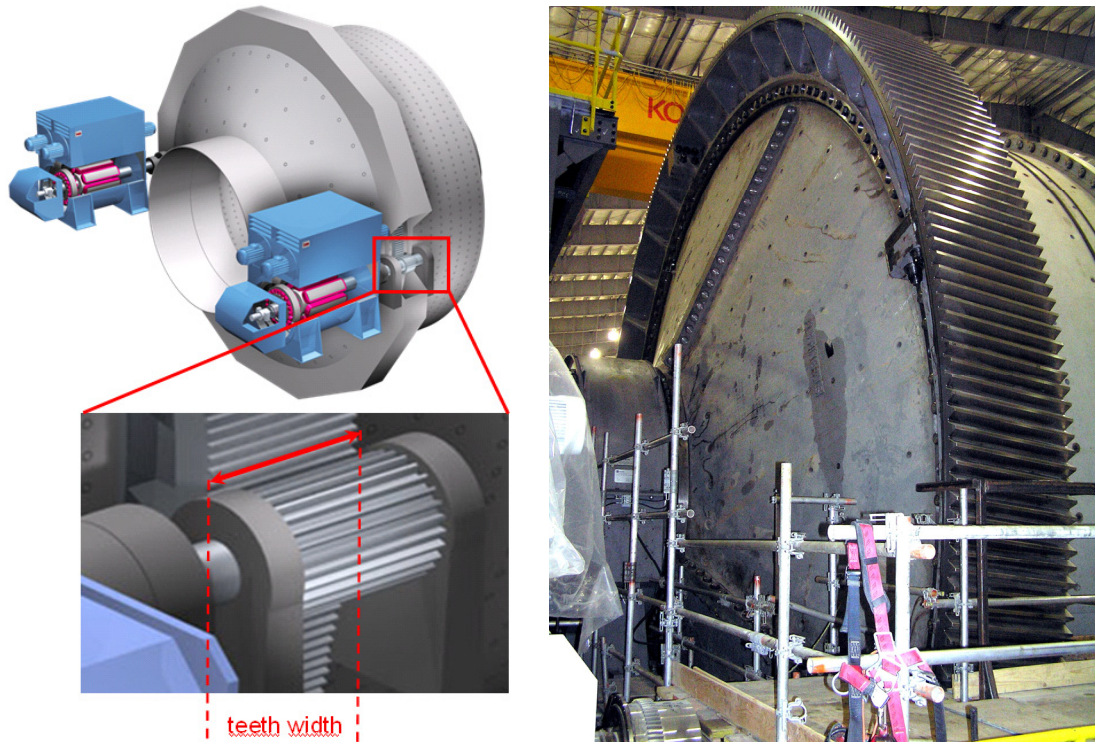


Figure 8 - Width of pinion & ring gear teeth

With wider teeth, alignment is not only more difficult, at the same time it will be even more important to reach perfect alignment, as the forces should be transferred ideally over the whole surface of the teeth; in the case of a non-perfect alignment, the forces will not be transferred equally over the whole tooth surface, but rather via hot spots. Today, for the largest mills, the teeth widths have reached almost 1.4 meter, which makes a perfect alignment practically almost impossible. Obviously with such wide teeth it will be more than beneficial to have always real smooth starts and without any torque spikes. In the case of the Copper Mountain mills this width is 1.016 meter for the SAG mill and 1.050 meter for the ball mills.

With the ABB solution, the two motors (master and follower) are capable of developing a high torque even during starting; in other words they can start the mill directly without the need of air clutches. Normally only a torque limiting coupling is used as common engineering practice, because the hypothetical worst case of a two phase short circuit on both motors at the same time could lead to huge opposite torques and could lift the mill out of its bearings. Unfortunately, exactly this has indeed happened on a certain dual pinion mill drive system using a complete different drive system technology from another drive supplier and which was not equipped with torque limiting couplings.

With the ABB solution, the start sequence is completely controlled by the drive system. The customers DCS can send a simple start command and the desired operation speed reference. The drive system will perform a smooth and safe start: first ramping up to a predefined starting speed, typically about 10% of nominal speed. While maintaining this speed, both the torque and the mill angle are monitored. Only if the mill controller measures cascading of the material, by a decreasing torque, before the critical angle is reached, does it release the drive to follow customers DCS speed reference. From then on, the drive is in the customer's hands, which means it will follow accurately any speed change requested by the DCS.

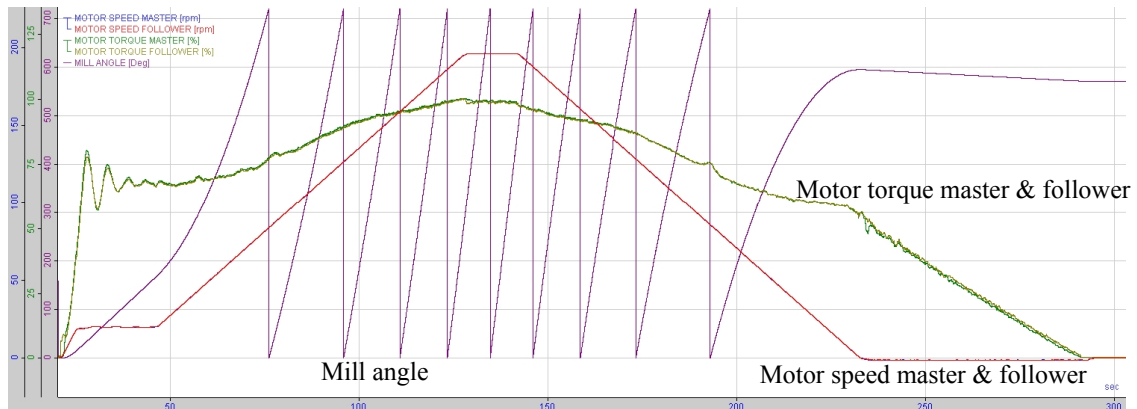


Figure 9: Smooth starting of dual pinion mill drive system (Copper Mountain Ball Mill 1)

Figure 9 shows a measurement of a normal start and ramping up to rated speed of Ball Mill 1 at Copper Mountain. It can be seen that the speed is slowly ramped up while the torque is increasing. The first small torque peak in the beginning is the break away torque. After that, the speed is ramped up slowly while the torque is increasing with the rotating angle of the mill. At an angle of  $36^\circ$ , the material starts to cascade with the first main torque peak of approx. 80% of rated torque, followed by some additional lower torque peaks. After this detection of cascading charge, the mill is released to continue running at low speed, until continuous cascade is reached. This is seen through the constant torque measured at the motor. At an angle of approximately  $180^\circ$  the mill runs stable and the mill controller releases the drive to follow DCS speed reference and therefore the drive starts to ramp up. It has also to be noted that the starting is extremely smooth for the mechanical components as no torque spikes occur. The motor torque is smoothly ramped up and the mill is gently brought up to speed. The maximum possible motor torque can be limited in the drive with separate levels for starting (higher torque limitation, e.g. 150% of rated torque) and for normal operation after starting (lower torque limitation, e.g. 110% of rated torque). In addition to the very accurate load sharing, Figure 9 contains two striking points. First interesting aspect is that the starting torque of this ball mill is about 78%, far below the rated torque level. Possibly this is a consequence of starting the mill extremely gently. The drive system has however been oversized to deliver 150% starting torque. The other fascinating issue is that this ball mill is apparently not a truly constant torque application, as the torque increases with the speed from about 70% of rated torque at 10% rated speed to rated torque at rated speed.

#### Frozen Charge Detection & Frozen Charge Remover

During start up of a mill, there is a potential risk of a frozen charge (more frightening also referred to as “dropping charge”) which can seriously damage the mill shell, mill bearings and/or other equipment. There are many examples of dropping charge events in the grinding industry, normally not with SAG mills but especially with ball mills, which ironically are often equipped without real frozen charge protection.

ABB's mill controller takes care of the starting sequence in such a way that the risk of a dropping charge is eliminated. If there is really a frozen charge in the mill, the drive will detect it on time, trip and perform a coast stop before the critical angle is reached. The frozen charge protection itself is based upon the fact that the torque comes down as soon as the mill charge cascades and that this must happen before the mill will have turned its first 90° rotation as can be seen in Figure 9.

The question is of course what can be done in case of a frozen charge has been detected and the mill has been tripped? Remove manually the frozen charge for example with a jack-hammer, a bobcat or similar? This will immediately lead to an extensive unscheduled downtime of the mill. Therefore ABB's dedicated mill functionality is not only protecting the mill from a dropping frozen charge, it also offers a function called *frozen charge remover*. Usually the first task for an operator after a frozen charge has been detected is to get the frozen material removed. The frozen charge remover function can only be initiated manually by the operator from a local control panel or from DCS. The frozen charge remover function tries to loosen the material by applying torque steps to the drive system. The optimal amplitude and the duration of the steps are found and set during the commissioning by ABB engineers. The amplitude of the torque steps are defined in a way that they are adding a certain percentage of the actual torque (not the rated torque) to the motors, while all the protection functions like torque and current limits are still active and working on the same levels as during normal operation. Therefore, the stress for the mechanical equipment never exceeds values that can occur during normal operation. After the frozen charge remover has stopped, a normal start can be tried. If frozen charge is again detected by the mill controller, the Frozen Charge Remover can be applied in the other direction. Figure 10 shows a measurement of the torque steps applied by the frozen charge remover function.

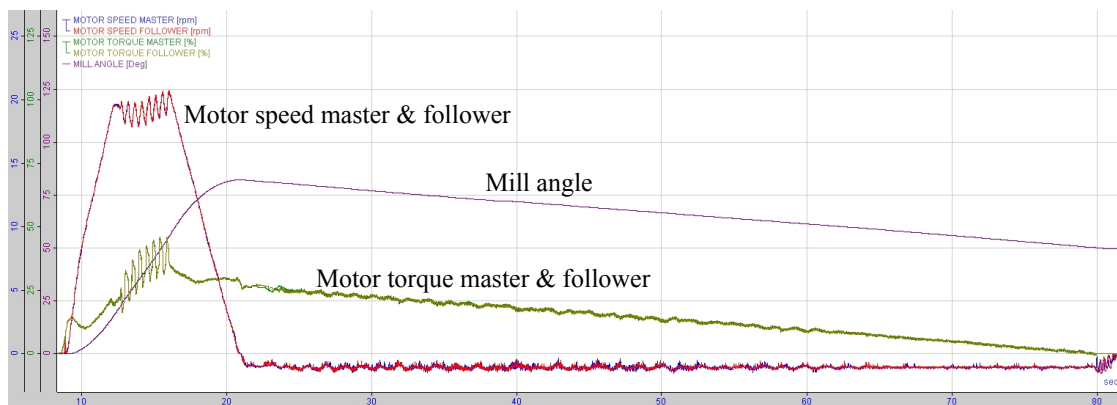


Figure 10: Frozen charge remover function (Copper Mountain SAG mill)

Soon after break away of the mill, torque steps are applied to the system. This is also reflected by speed changes, quickly accelerating and decelerating. The torque step amplitude can be adjusted during commissioning. It can also be seen, that torque as well as speed are always positive and therefore no backlash phenomenon occurs between the pinions and ring gear. If backlash would happen, it would be seen by a drop in torque to zero or even negative values, but since torque and speed are always positive, operation is always in the same quadrant (first quadrant: positive speed, positive torque). In other words, the contact between pinion and ring-gear is always maintained.

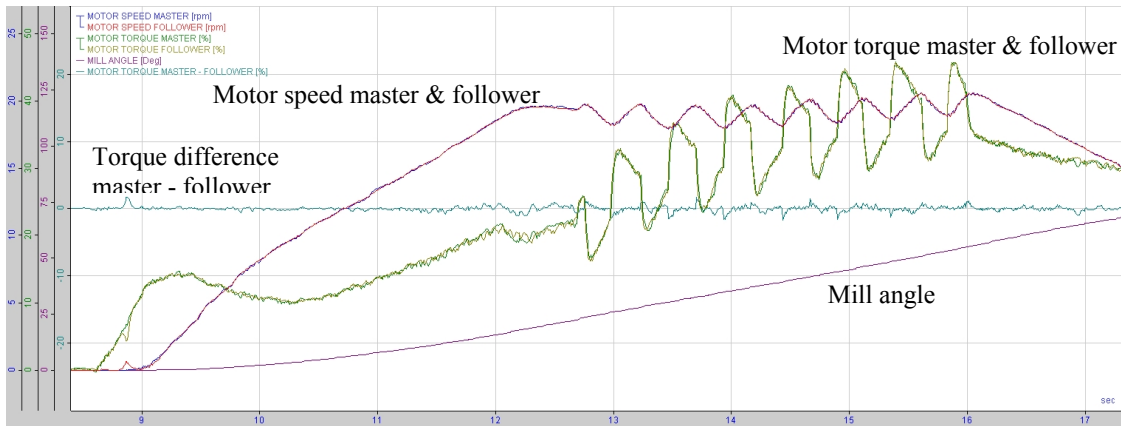


Figure 11: Close up of frozen charge measurement (Copper Mountain SAG mill)

Figure 11 shows a close up of the measurement shown in Figure 10. This gives a very clear picture of the accuracy of the load sharing during the demanding frozen charge remover function: with relative low speed (20 rpm motor speed, about 10% of rated speed) the torque of the master and the torque of the follower are almost overlapping each other; even during the quick torque steps the torque of the two motors are perfectly in phase. It can also be clearly observed that there is absolutely no backlash occurring.

### Inching

Inching (or creeping) is a common maintenance function for mills. It provides the advantage of turning the mill at very low speed for maintenance purposes - like visual inspection of bearings or manual positioning for liner change. Mills using fixed speed motors for the main drive system need an auxiliary motor with a reduction gearbox to perform creeping. ABB's mill drive systems however can provide high torque at low speed and therefore inching is possible with the main drive. To start inching, the operator can pre-select the inching mode and direction of rotation, followed by a start command. A speed reference is not required, because the mill controller will start up to a low constant speed. The start procedure is, again, completely controlled by the mill controller, similar to the normal start. This means that also frozen charge detection is activated when inching mode is selected. Figure 12 shows the inching procedure of Ball Mill 1 at Copper Mountain, where the inching speed is set to 0.20 rpm mill speed (1.68% of rated speed 3.293 rpm motor speed).

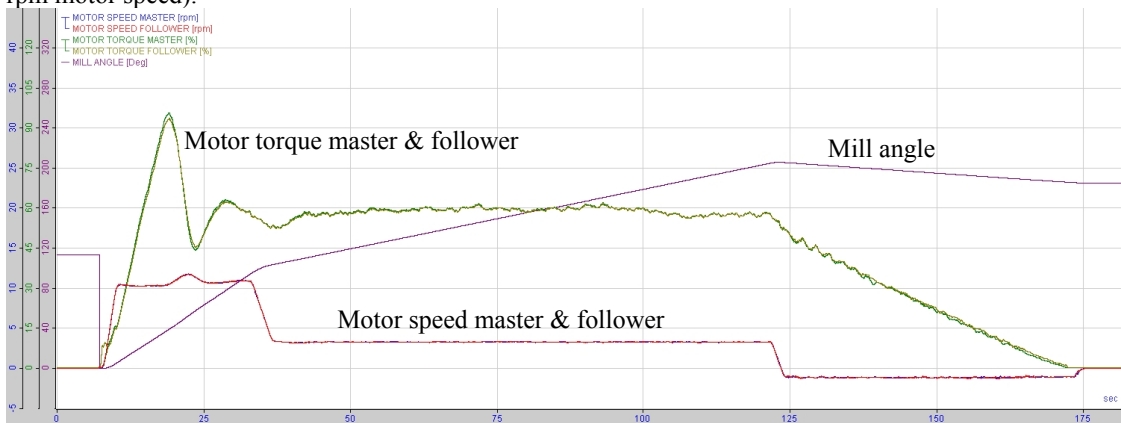


Figure 12: Inching with 0.20 rpm mill speed or 3.293 rpm motor speed (Copper Mountain Ball Mill 1)

The mill first ramps up to about 5% of rated speed, until cascading is detected. Then the speed is being reduced to the predefined inching speed.

### Control Roll Back

When the mill is stopped, then the charge in the mill is in an unbalanced position and typically the mill will start to rock forward and backward for several minutes. ABB has implemented the so-called controlled roll back function as found in the GMD control functionality. The corresponding measurement of a controlled roll back operation on Ball Mill 1 at Copper Mountain is shown in Figure 13.

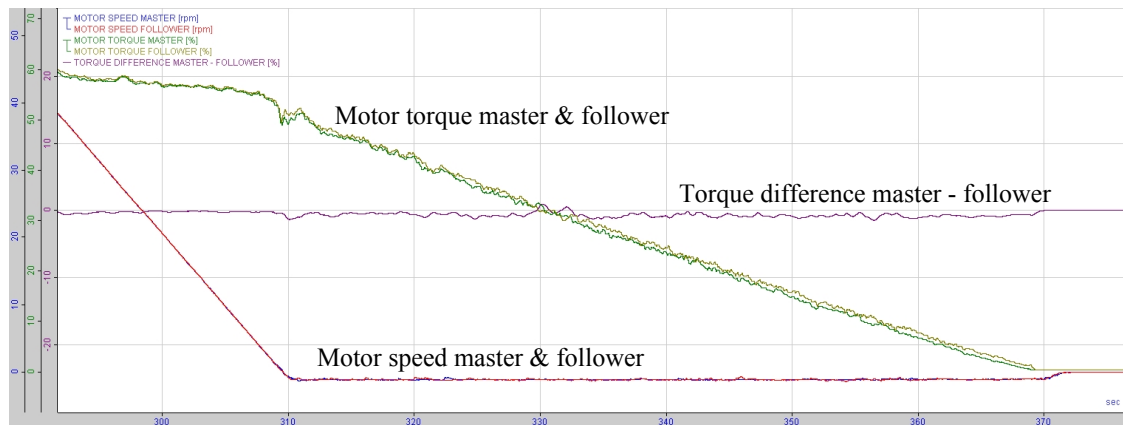


Figure 13: Controlled roll back (Copper Mountain Ball Mill 1)

After the mill controller receives the stop command from the DCS, it starts to ramp down the speed. When zero speed is reached, the mill has stopped but the torque is still at a high level because of the unbalanced mill charge. Then the drive system starts slowly in the reverse direction to roll back the mill until no torque is remaining in the system. During this time, the motor is acting as a generator, taking back the potential energy which exists in the system due to the material which is still lying in the mill with a certain angle. The braking energy will be dissipated by the losses in the motor, pinions/ring gear and inverter. Because these losses are quite limited, the mill speed during this control roll back is fairly low: the motor speed is about 1 rpm, which corresponds to about 0.5% of rated speed or 0.05 rpm mill speed. Even with this extremely low speed, the superior load sharing is still functioning perfectly. The drive is rolling back the mill in about 62 seconds.

Just to compare, Figure 14 shows a measurement where the mill was stopped without the controlled roll back procedure and was rocking forward and backward for several minutes; finally the mill stopped after 217 seconds.

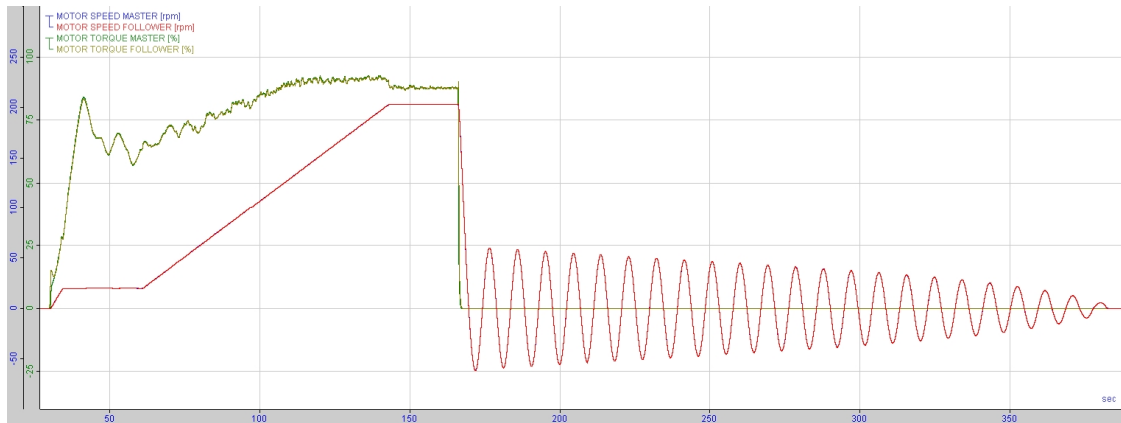


Figure 14: Stopping of the Copper Mountain SAG mill without controlled roll back (coast stop)

### Automatic Positioning

This controlled roll back functions opens the door to position the mill accurately and automatically. The automatic positioning function allows the operators to turn the mill by any desired angle or number of liner rows. It is a very helpful function during liner replacement. Ideally, this command is initiated by a local control panel, located close to the mill. Alternatively, it can also be done from the DCS. The operator can pre-select positioning mode, preferred direction of rotation and set the desired angle, or number of liners. After that, only the start command is required and rest will be performed by the mill controller. Due to the controlled rollback function, the mill ends up in the desired position without any torque remaining in the system. The sequence stops automatically and switches off the drive after the position is reached. Of course, a forced stop command can be given at any time also during the positioning routine is still running. After the drive has received the mill angle reference and the start command from the local control panel or the DCS, it starts to slowly ramp up to speed. The function is implemented in such a way, that the cascading angle of the material is considered. Together with the controlled rollback, a torque free position can be reached very accurately. Figure 15 shows measurements with the automatic positioning function, where a 90° turn was requested.



Figure 15: Automatic positioning routine with 90° angle reference (Copper Mountain SAG mill)

It can be seen, that the material cascaded at 46° with a torque peak of 69% of rated torque. The drive keeps running on a constant low speed (about 20 rpm motor speed, corresponding to roughly 1 rpm mill speed or 10% of rated speed) for a certain time and then starts to ramp down. By reaching zero speed, the mill has turned almost 125°. At this point of time, the torque value is over 70% of nominal torque,



which means the mill stopped in unbalanced position. Now the drive starts to run in reverse direction, reducing the torque slowly. Only when zero torque is reached, the drive will stop. The mill has finally turned 90.4°, which is an inaccuracy of only 0.4% and the total time for the complete sequence is only 130 seconds. Therefore it can be clearly said, that the automatic positioning function is faster and much more accurate than manual positioning; consequently the downtime for liner change can be reduced and higher mill availability is achieved.

### Accurate Load Sharing

All the above mentioned features are truly useful and valuable features for operator and they are available for both single and dual pinion mill drives. But for the dual pinion mills the drive system also the load sharing of the two motors has to be fast and very accurate. A measurement taken on Ball Mill 1 at Copper Mountain showing the amazing accuracy of the load sharing is presented in Figure 16.

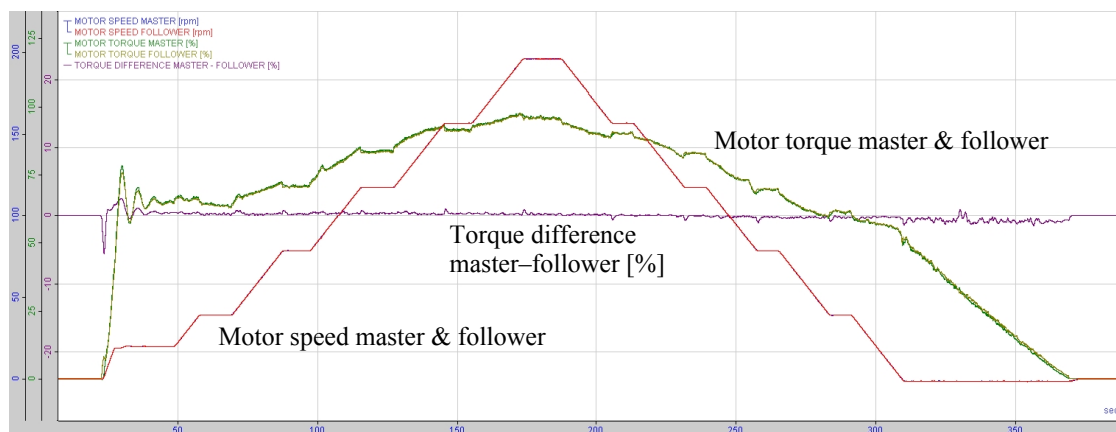


Figure 16: Torque difference between master and follower motors (Copper Mountain Ball Mill 1)

For this measurement the mill was started and then driven at several different speeds and finally stopped with a controlled roll back. In this measurement a synthetic signal was created, by subtracting the master motor torque from the follower motor torque. During the whole operation area, the torque difference between the two motors is below 1% of the nominal torque. Only during break away in the beginning the torque difference is about 5% (maybe the teeth of one pinion and the ring gear did not make full contact before starting) and during the controlled rollback procedure, when the mill speed is extremely low (0.05 rpm), the torque difference is slightly larger, but still clearly below 2%. Also Figures 11 and 13 show the amazing load sharing achievements in close up mode of a controlled roll back and a frozen charge remover procedure. It has to be noted that the peaks shown in this Figure 16 are not torque peaks or torque spikes as such, but show only the relative difference in the actual torque values of the two motors. Therefore it can be concluded that the load sharing between the two motors is functioning both very accurately and smoothly.

### Electrical Friendly

The typical direct-on-line motors have a high starting current, larger than the rated motor current. In the case of a fixed speed direct-on-line synchronous motor, this can easily be in the range of 6 to 8 times the rated current, which could lead to voltage stabilization problems for the whole plant. However with the ABB drive solution the current drawn from the supply network during the starting of the mill is very low. First it has also to be noted that when starting the motor with relative low speed (about 10% of rated speed), the required torque until the mill charge cascades can be high (for example 150%), but this means that the required real power is relative low. For example when 150% starting torque is required in order to start a fully loaded mill, then the corresponding starting current on the network side is in the range of about only

15%. This is reached thanks to the concept with the ACS 6000 converter, which basically decouples the motor from the feeding network. To reach 150% starting torque, also 150% rated motor current is required, which is supplied by the ACS 6000. When starting, both the motor frequency and the motor voltage are low and the motor current is high. But on the network side it is just the opposite: the network frequency and the network voltage are high and the current drawn from the network is low. Figure 17 clearly demonstrates this with a measurement of the network current on the primary side of the converter transformer.

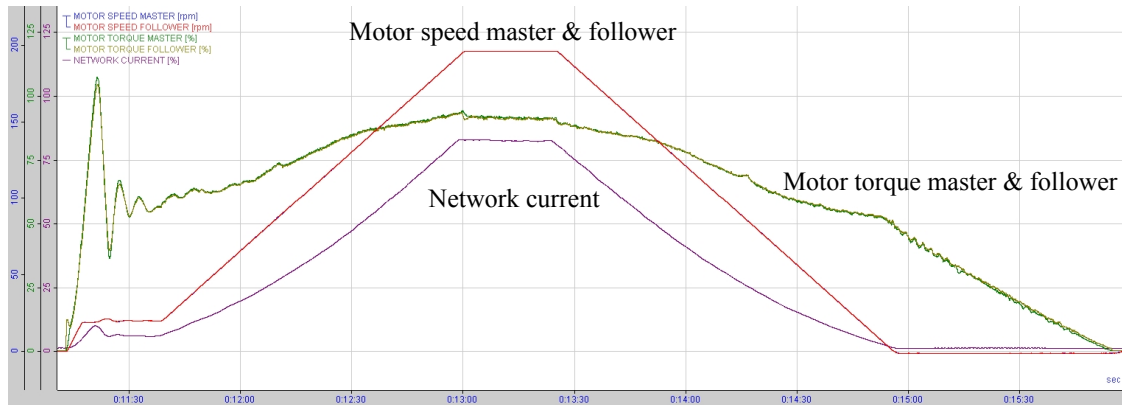


Figure 17: Network current measurement (Copper Mountain Ball Mill 2)

This measurement of a starting, accelerating, decelerating and stopping procedure was recorded after a relative long stop of the ball mill with load. Therefore in this case the starting torque is relative high (107% of rated torque) compared to the earlier shown measurements, but still far away from the design value of 150% for the starting torque. The current shown in Figure 17 is the current measured on the primary side of the converter transformer and it can be observed that even for this 107% starting overload, the current drawn from the 25 kV bus is with about 10% of rated current very low.

Furthermore the drive concept with the ACS 6000 and converter transformers has another intrinsic advantage: supply voltage flexibility. The maximum possible motor voltage of direct-on-line motors is 13.8 kV, as where with the ABB solution, the client is completely flexible to use any supply voltage for the mill drives up to 36 kV. This flexibility can be freely used by the electrical engineer designing the electrical distribution of the plant leading to several benefits such as lower current ratings for the switchgear and avoiding another distribution transformer together with its corresponding losses. In the case of Copper Mountain, the voltage level for the mill drive systems was raised to 25 kV.

### Variable Speed

It is a well accepted fact that SAG mills do require variable speed drives. But the same can not be said for ball mills. Therefore this was not a must have on the target feature lists for the ball mill drives when ABB developed its sophisticated dual pinion mill drive system; variable speed for ball mills was rather considered a nice-to-have feature. But due to the superior technology used for the new mill drive system, the variable speed was as an intrinsic feature anyway automatically available for the operators. After numerous discussions with operators, process engineers, metallurgists, consultants and others, ABB came to a totally different conclusion: although variable speed for ball mills is not an absolute must, it can not be considered as only a nice-to-have feature, but it is exceptionally beneficial. Evidently some examples are required to underpin this statement.

ABB is in the fortunate position to be the market leader for the huge gearless mill drives (where the motor is wrapped around the mill and by doing so not only eliminating the gearbox, but also the pinion and ring gear), which also provide the possibility to smoothly vary the mill speed. The ball mills in Latin

American concentrators are often equipped with gearless mill drives; hence the operators do have the possibility to vary the ball mill speed. And as a matter of fact, they are truly using this possibility! Figure 18 shows the speed histogram for about two months of the SAG mill (left side) and one of the ball mills (right side) in a copper concentrator.

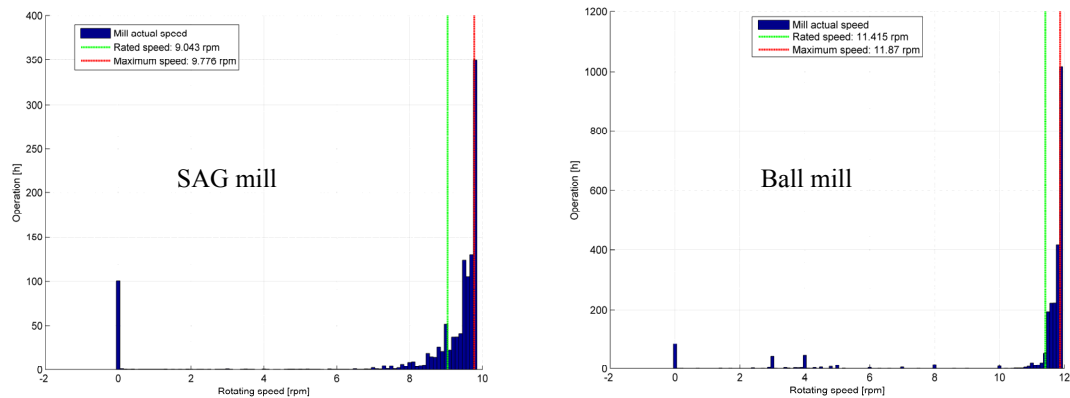


Figure 18: Approx. two months mill speed histograms in a South American copper concentrator

It can be unmistakably observed that for this SAG mill during these two months the variable speed feature on the SAG mill is used, the mill speed is varied between around 7 and 10 rpm. This is not surprisingly, as it concerns a SAG mill. But also the speed histogram of the ball mill shows that the variable speed feature is used, although in a smaller operating range. Interesting is also the fact that, for no matter what reason, the ball mill is typically running at a different speed (rather faster) than the original designed rated speed! Exactly this was seen by Copper Mountain as a huge advantage: to be able to run faster than the rated speed without changing the pinions on the SAG mill.

In addition, the other astonishing detail presented by the ball mill speed histogram on the right hand side of Figure 18, is the fact that the ball mill is sometimes running at very low speeds (3 - 8 rpm), that there will be no grinding at all: the balls and the ore are just tumbling in the mill. The motivation behind this unexpected phenomenon is the following. Sometimes there is for some reason no ore feed to the ball mill; this can be caused for example by required inspections performed on the SAG mill (shell, bearings, etc.), which leads to a relative short shutdown of the SAG mill.

If the ball mill would be equipped with fixed speed motors, then they will have to be washed out, isolated and stopped. Otherwise by keeping the ball mills running with full speed, without new ore entering the ball mill it would end up in a mill grinding its own balls. However with the possibility to vary the speed of the ball mill, the operator has suddenly a new possibility: the speed of the ball mill can be reduced to such a low level that no grinding is taking place, the balls and the ore are just tumbling, but the ball mill remains in operation. Whenever the ore feed to the ball mill is recovered again, then the ball mill speed is immediately ramped up and the length of downtime will have been minimized. Exactly this interesting aspect has indeed already been used extensively by Copper Mountain during the first weeks of operation when ramping up the production.

The last example is looking at it from a different perspective: when developing a new concentrator, first a lot of drilling will be performed to achieve ore samples. These required ore samples are tested, maybe with different methods, resulting somehow in the design of a specific grinding circuit, which is optimized for certain assumptions. If everything is exactly as expected, i.e. the ore is exactly as expected, both the primary and secondary crushing are performing exactly as expected and the same applies for the SAG mill (or in some concentrators high pressure grinding rolls), then indeed no variable speed will be required for the ball mills. But the world is not always perfect and therefore it could be very beneficial to have some flexibility in the last stage of the grinding process in order to avoid not only inefficient re-

circulating loads, but to avoid also over-grinding. Furthermore with increasing depth of the pit, typically the ore is getting harder. Without the speed flexibility on the ball mills, the operator would somehow have to live with the available options and can only just either add balls (but not take them out easily) or switch on / switch off the ball mills and therefore most likely will end up sometimes with either re-circulating loads or with over-grinding. But with higher flexibility levels in the grinding process ABB has lifted the flexibility and possibilities of the operators to a much higher level, which enable them to increase the overall grinding efficiency.

## CONCLUSIONS

Copper Mountain has a conventional grinding circuit with one SAG and two ball mills, all driven by a sophisticated low speed mill drive system with extremely accurate load sharing capabilities. The drives provide unique and practical features for the dual pinion mills and enable great flexibility in their operation. Some of the selected mill drive inherent features were in the specific case of Copper Mountain rather nice-to-have features, of which the real added value was questioned, where other features were considered to be essential. Copper Mountain will have the possibility to use the variable speed not only on the SAG, but also on the ball mills and will be able to run each of the mills not only at a lower but also at a higher speed than the originally designed rated speed. Copper Mountain will have the possibility to continuously optimize the efficiency of its complete grinding circuit. The three dual pinion mill drives have been commissioned successfully and the plant went into production in June 2011.

## REFERENCES

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