VFD CONTROL METHODOLOGIES IN HIGH PRESSURE GRINDING DRIVE SYSTEMS

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ABSTRACT

High Pressure Grinding Roll (HPGR) technology is a reliable workhorse in the cement industry. Because of its generally overall lower cost per ton of material processed, HPGR applications have been growing in popularity in recent years in the mineral processing industry. HPGRs can be combined with variable frequency drives (VFD) to provide added process flexibility and reduce roll wear rates. This flexibility and reduced wear can increase uptime and overall mill throughput. The nature of the HPGR mill design with its independent grinding rolls requires an innovative solution for the control of the rolls when driven by a VFD. This paper reviews available drive control methods to determine a solution that will promote low roll wear and maximum grinding efficiency.

INDEX TERMS

Control Design, Control Engineering, Mining Equipment, Power Conversion, Torque Control, Variable Speed Drives.

HPGR MACHINE TECHNOLOGY

High Pressure Grinding Roll crushing equipment consists of several major components as shown in Figure 1.

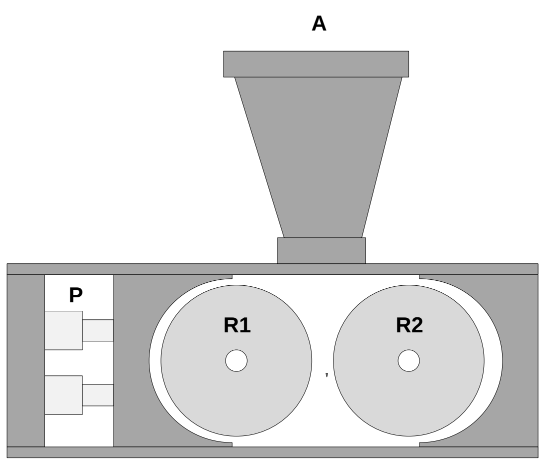

Figure 1 – HPGR Cross-section

Material enters the top of the mill by gravity feed as shown at A. Rolls R1 and R2 are independently driven. The crushing zone is between the rolls formed by the gap between the rolls. The gap and the pressure exerted on the material are set by the horizontal rams shown at the left at P. While each roll is driven independently, overall they must act as a connected system when material is being ground between the rolls. Over time the rolls may not wear at the same rate, resulting in different diameters for the rolls. This presents a challenge in that it is necessary to maintain the same tangential velocity at the

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roll face for both rolls. Failure to maintain the tangential speed equivalent between the rolls will result in excessive wear and necessitate more frequent roll changes.

HPGR MILL DESIGN

Mill design seeks to minimize roll wear for long life and maximum uptime. One important factor in optimizing this design is to assure the two rolls maintain the same tangential speed at the roll surface. The roll tangential surface speed in feet per minute can be calculated as:

$$Speed = Roll\ RPM \times \pi \times Diameter$$

The necessity of maintaining the same roll face tangential speed becomes clear when one considers that the material between the rolls effectively connects the rolls. Different surface speeds will cause the slower roll to slip with respect to the material whose speed would be set by the faster roll. As rolls wear, the roll with the smaller diameter will decrease further, and the same roll RPM will produce an even lower lower roll surface speed. This uneven roll wear increases the speed mismatch and roll wear will accelerate.

HPGR DRIVE CONTROL METHODS

There are several potential methods to control the HPGR motors using a variable speed drive. Different drive regulator schemes as well as how these regulators could be used in combination will be examined. Most modern drives are equipped with a speed regulator and a torque regulator. These different regulators will be summarized in the analysis that follows to determine which control configuration might give the optimal results. Each method must consider the basic design goals of HPGR mill design.

CONTROL METHOD 1 – INDEPENDENT SPEED REGULATORS

The most straightforward way to control the rolls is to have both drive 1 and drive 2 operate as individual speed regulators. In this arrangement both roll 1 and roll 2 drives will receive a speed reference from the mill control system. This is shown in by the red lines in figure 2 below. The speed regulator of each drive compares its speed feedback with the speed reference and makes adjustments as necessary until the speed feedback is equal to the speed reference. This is done by each drive individually, without consideration to the actions of the other drive. This is shown in figure 2, where the speed regulators in Drive 1 and Drive 2 will receive the same speed reference but will act individually to match its output speed to the speed reference.

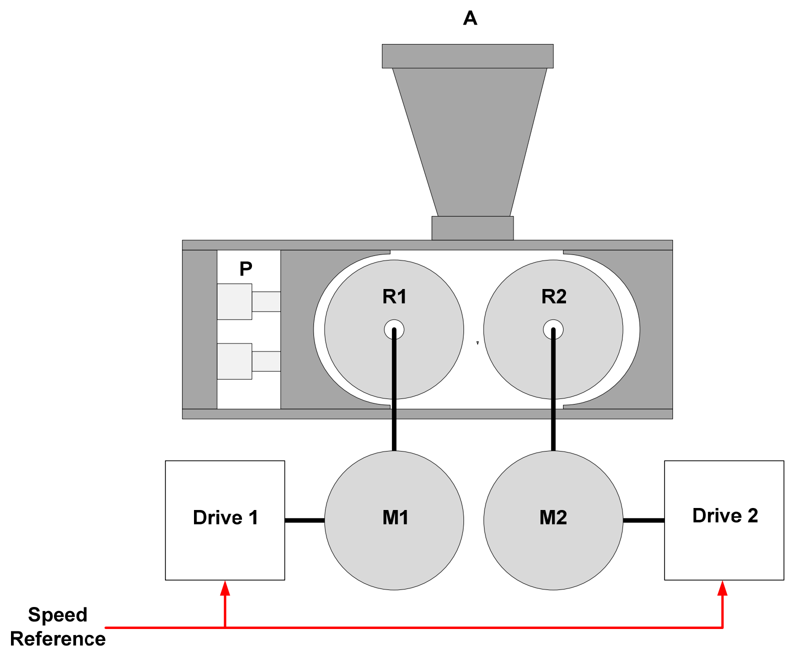

Figure 2 – Independent Speed Regulator Signal Exchange Diagram

Even when the same model drive is used for both rolls there will be some small differences in their output. Sensorless vector control models the physical characteristics of the motor and calculates motor magnetizing and torque current independently. It will utilize this model to control motor speed reasonably accurately, but will still leave some potential for error. Most drives have a nominal sensorless vector speed accuracy of +/- 0.5% or better for each drive without a speed sensor. This results in a maximum error of +/- 1.0%. If a speed sensor is utilized to measure speed directly it sends an accurate speed signal back to the drive. Similarly to sensorless vector control, a full tach-vector control models the motor within the VFD processor using the physical characteristics of the motor. Combined with the speed signal feedback this can reduce the potential error to +/- 0.01% for each drive giving a maximum error of 0.02%.

In either of the referenced types of speed regulation the roll diameter is not considered. As rolls wear over time and any initial variation in roll diameter is taken into account, the potential speed mismatch increases further. The rolls will not share load evenly, resulting in relative slip and excessive wear. This could be overcome with a continuous measurement of roll diameter, but this would introduce measurement errors and add additional cost and complexity to the system. The measurement of each roll diameter would have to be used to scale the speed reference for each drive individually. This means two separate speed references would have to be maintained. In the end, this would not fix any error in the speed regulators. In summary, independent speed regulators would work a as a control method, but would not be optimal.

CONTROL METHOD 2 – TORQUE REGULATION

Another method of controlling the drive is to utilize a torque regulator. In this case a torque reference would be sent to each drive from the mill control system. The drive system would function similarly to figure 2, with the torque reference replacing the speed reference. Both a speed regulator and torque regulator seek to control the current supplied to the motor. The amount of torque generated by the motor is proportional to the amount of current supplied by the drive. The torque generated will determine the speed of the motor and its connected load. The difference is that a speed regulator is given a speed target to meet while a torque regulator is given a torque target to meet, regardless of speed. This raises the main issue with using a torque regulator alone: that while operating the system if the supplied torque is greater than load torque the motor and load will accelerate, and conversely any time the load torque exceeds the supplied torque the system will slow down. The result would be a constantly changing mill speed as the uniformity of the feed stock varies, which will impact machine throughput and process control. Plant control systems are defined based on speed, and not torque, to maintain a given throughput. Using a torque regulator would require an additional method to control mill speed. It is easier for an engineer or operator to understand a process speed setting rather than a torque setting.

In this case the drives would share load evenly since both drives would produce the same torque. When material is being ground and the rolls are effectively connected they would rotate at approximately the same speed. This would take into account any variation in roll diameter that would develop over time. However, speed will vary as the load torque requirement changes. Additionally, when starting the mill unloaded, the torque supplied would exceed the inertia of the system and would tend to over-speed. The only constraint on roll speed would be any over-speed protection built into the drive. In summary, a torque regulator on its own would not be a reliable control method for this system.

CONTROL METHOD 3 – MASTER/FOLLOWER ARRANGEMENT

An effective solution for this system can be found by utilizing a combination of speed and torque regulators. In this configuration, when the system is started both drives are controlled using independent speed regulators. As the mill is loaded one of the drives is transitioned to a torque regulator. This is possible utilizing internal logic built into the drive and proper configuration fo the drive I/O for this application.

Startup: While starting the mill both drives are controlled independently using each drive's speed regulator. This is necessary because until the mill is loaded the rolls are not connected. If the roll drives were controlled using torque regulators only there would not be anything to constrain roll speed aside from any over-speed protection. Starting as speed regulators allows the rolls to be brought up to operating speed in a controlled manner and made ready for production. The speed reference from the control system is wired to both drives to enable this mode of operation, shown in Figure 3 as a 4-20 mA analog signal. Figure 3 shows a more detailed signal exchange diagram for the roll drives.

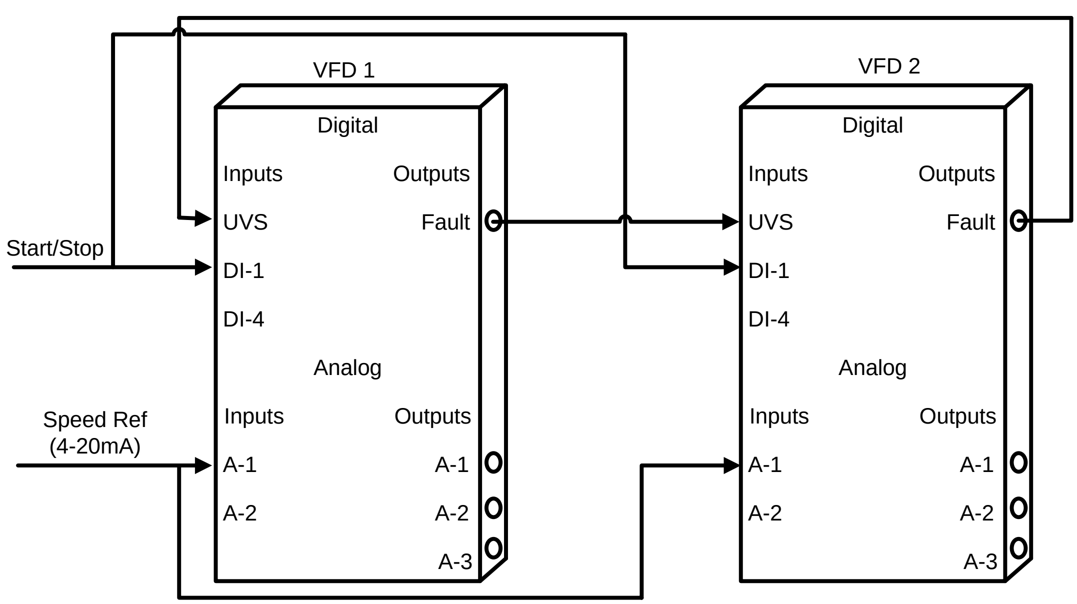

Figure 3 – Mill Startup Signal Exchange Diagram

This diagram shows the signals exchanged during the mill startup phase. Analog signals are represented by an "A" followed by a number designator. "DI" represents a digital input. "UVS" is the under-voltage relay for the drive which will trip the drive. "Fault" is a digital signal sent from the drive when it trips.

Production: During the production phase when there is material in the mill the drives are controlled differently, one as a speed regulator and one as a torque regulator as shown in figure 4. The speed regulating drive is defined as the "Master" while the torque regulating drive is defined as the "Follower" drive. This signal exchange is shown in figure 4 where VFD 1 is the master drive and VFD 2 is the follower drive. The master drive continues to read the speed reference from the control system and will maintain the speed requested. The follower drive continues to receive the speed reference and ignores it. Instead, the follower drive reads a torque reference from the master drive. This is shown in figure 4 as the A-2 output from VFD 1 to the A-2 input to VFD 2. The follower drive matches the torque reference so that it shares load evenly with the master drive without directly controlling the speed of the follower drive's motor. This arrangement results in effective load sharing and minimizes roll wear.

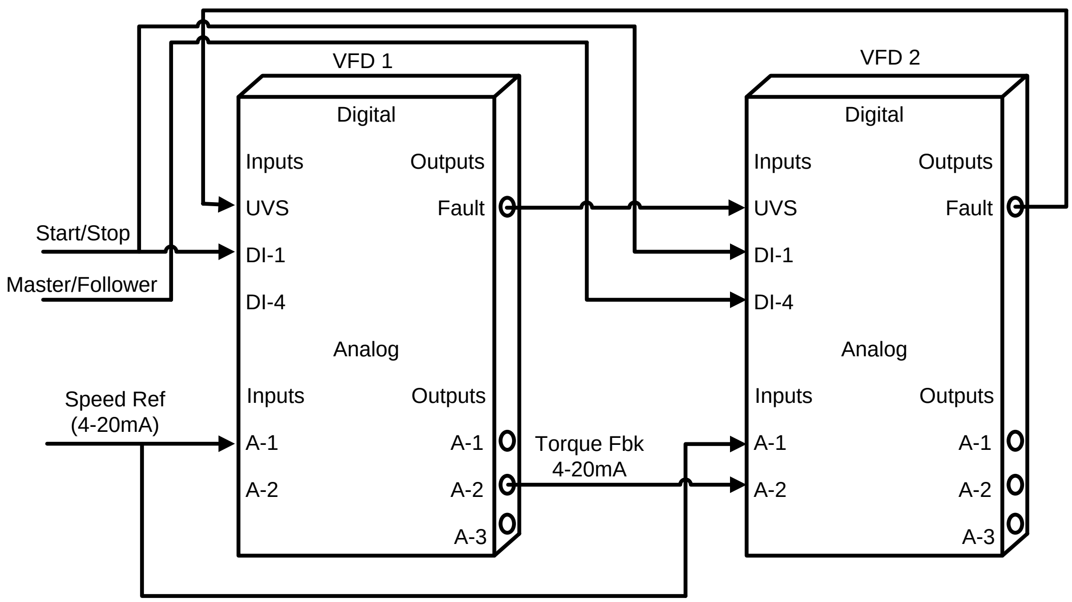

Figure 4 – Mill Operating Signal Exchange Diagram

Transitioning: The transition from speed regulation to torque follower mode for the follower drive is controlled by mill loading. When load in the Master drive reaches approximately 30% a digital output will activate under drive software control signaling that the mill has picked up load. The 30% threshold is a software parameter that can be adjusted as needed. There is a corresponding output in the follower drive that will activate as well at 30% load. A time delay relay in VFD 1 will be energized when the load contacts from both drives register the required amount of loading and after the time delay on pick up expires. A normally open contact from this relay is wired to the follower drive input DI-4 to switch the follower drive into torque follower mode. If mill loading drops below the preset threshold, the load relay will drop out and the follower drive reverts to speed regulation. This transitioning protocol is performed to ensure that there is adequate load to prevent the follower drive from reaching an overspeed situation since the drive is not controlling speed directly. This protocol also prevents the follower drive from overspeeding in the event the mill is completely unloaded. Figure 5 shows the signal exchange for transitioning from speed regulation to torque follower mode.

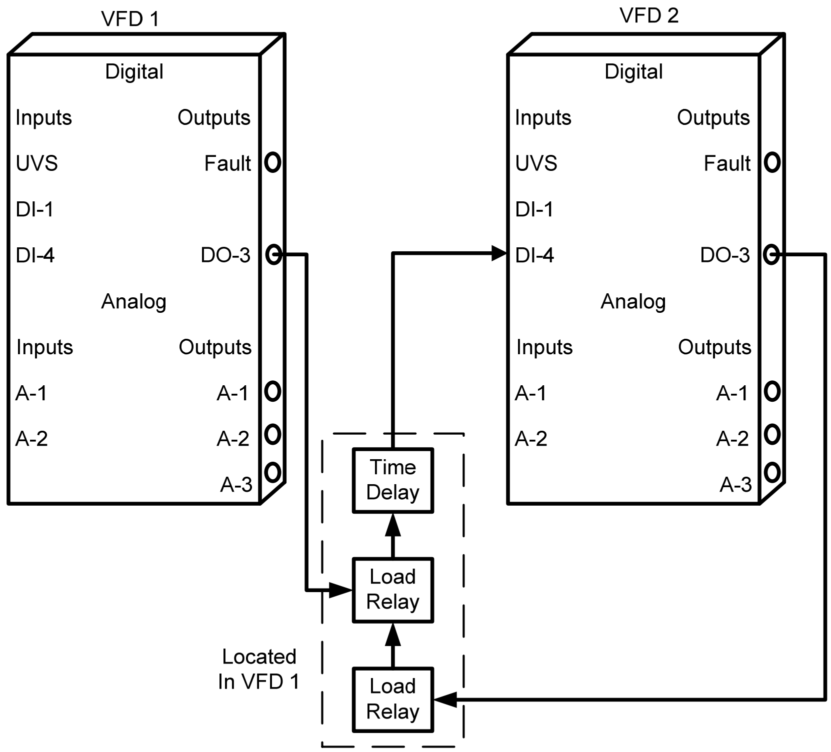

Figure 5 – Transition Signal Exchange

As an added safety feature to protect the follower drive from overspeeding, an “Or Regulator” may be utilized in the follower drive. This regulator compares the speed of the follower drive to the speed reference. If the follower drive speed increases by a preset limit above the speed reference the follower drive reverts to a speed regulator. This will prevent the motor from overspeeding due to some unforeseen circumstance. This function operates independently from the load relays.

Additional functionality: The drive setup shown in figures 3, 4, and 5 can be enhanced to include the ability to have either drive act as the master drive. Several steps are required to enable this capability. First, the speed reference is sent to both drives, and torque feedback is also sent to both drives. Second, the output of the time delayed load relays is also sent to both drives. The user definition of which drive acts as the master can be accomplished by any number of means including an HMI input that would trigger an output from the mill control system or a physical switch on the drive panel. In a recently installed system for example, a selector switch was installed on one of the drives that had a position for Drive 1 and another for Drive 2. A digital input on both drives reads the output of this switch. This input, when activated works in series with the load relays and time delay to switch the drive defined as the follower to torque follower mode once the load requirement is reached. This system ensures that no field re-wiring is necessary to change which drive is defined as the master.

With or without the master drive selection enhancement the master/follower control method gives the best of both worlds for the HPGR system. It takes advantage of the independent speed regulator’s benefit of starting the mill unloaded while maintaining speed. Once the mill is loaded the torque regulator is used in concert with the speed regulator to maintain the desired speed as well as share load evenly between the rolls and minimize roll wear. This coordinated control system gives the best performance for the HPGR system.

CONCLUSION

We have reviewed several possible methods to control the HPGR motors using variable speed drives. Operating both drives with independent speed regulators will result in a potential speed mismatch that cause uneven load sharing and accelerated roll wear. Utilizing a speed regulated master drive with a torque regulating follower drive results in even load sharing and better speed matching. This is accomplished because the speed regulator will control rotational velocity for the master roll while the follower roll matches torque for optimal load sharing. The improved speed match between the rolls is due to the torque regulator ignoring the speed reference and instead relying on the physical connection between the rolls that results from the material being ground effectively joining the rolls.

This approach is the optimal method for controlling an HPGR system with independent roll drives. It utilizes capabilities available in every drive that comes off the production line and does not require any special equipment or monitoring capabilities.

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