Radomiro Tomic Tripper Drive and Local Control System

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In 2001, the Radomiro Tomic Mine located near Calama, Chile, added a tertiary crushing facility. An 84" wide mobile tripper is used to fill their tertiary crushing storage facility. This paper is a case study to demonstrate the drive and control systems in use on the tripper. Of special note is the design concept used to allow the system to operate multiple motors in both demand and regenerative modes through a single VFD. Also noted is the use of touch screen local controls, handheld radio controls, starting/stopping/braking philosophies, safety device interfaces, and the local to remote control interface.

OVERVIEW

The Radomiro Tomic Tripper is designed to continuously discharge 8,050 metric tons per hour of crushed copper ore into a storage facility. To fill the complete length of the storage facility, the tripper travels a length of 46 meters. Special design features include a non-slip soft start, dynamic braking (regenerative drives), multiple motors driven off a single variable frequency drive (VFD), a touch screen local control panel, handheld radio controls for maintenance, starting/stopping/braking philosophies, safety device interfaces, and a local to remote control interface.

Eight wheel assemblies, four per side, are used to support the weight of the tripper. The amount of torque that can be transmitted through a single wheel assembly is directly proportional to the amount of weight supported by that assembly. The four center wheels handle the largest proportion of weight, the front wheels second and the rear wheels the least. Based on the distribution of weight on each wheel, we decided that the four center wheel assemblies would be powered and front and rear wheel assemblies would be followers. This allows the drive system to deliver enough torque to accelerate and operate the system without wheel slippage under normal conditions. It also provides enough drive torque transmissibility to start and operate the tripper under unintentional adverse conditions (i.e., material buildup on a section of the rail, one drive removed for maintenance...).

Smaller NEMA B motors have starting torques that can exceed 200% of their nameplate full load torque. This raised the question, how can we ensure that the starting torque of each motor does not exceed the amount of torque that each wheel can transmit without slipping?

VARIABLE FREQUENCY DRIVE

The option of a variable frequency drive (VFD) was considered. A VFD provided the ability to control both torque and speed. By limiting the torque to a point below the wheel slip point, and by ramping the speed, we could soft-start the system. A VFD would allow for soft starts that could protect the wheels from slipping and give greater life to the drive components by minimizing shock loads that can be created by high starting torques.

A year or so earlier, we had the opportunity to upgrade an existing tripper that a client had been operating for some years. Their control system included a VFD system similar to the one proposed for the Radomiro Tomic project. Unfortunately, the existing tripper was going into an overrunning or overhauling state. In this state the tripper would overspeed the motors and "runaway" down the track. There are two primary causes for an overrunning condition. The first, and most significant, is a downhill slope to the tracks. The second is the forward running forces caused by the transition from the horizontal belt line to the sloped belt line of the tripper section. Normally there is enough friction in the system (belt scraper, wheel bearings, drive efficiencies, etc.) to prevent a full belt from pushing the tripper down the tracks. However, when combined with a slight downhill slope, this could cause an overrunning condition. The VFD control system was not designed to handle an overhauling condition and was not detecting this "runaway" condition. Eventually the tripper would reach its end-of-travel limit switch and engage the emergency/parking

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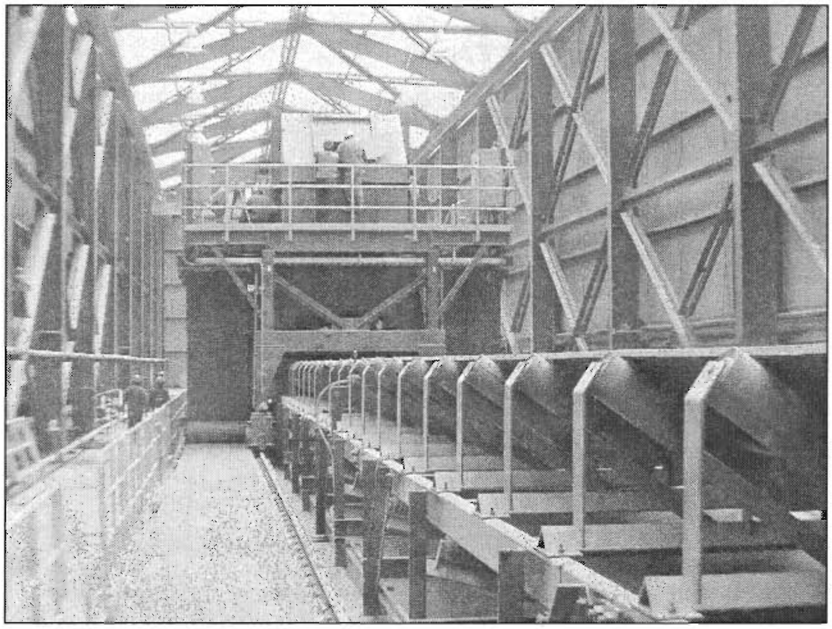

FIGURE 1 Radomiro Tomic Tripper during commissioning

brake. However, the inertia developed in the overrunning condition caused the tripper to ram into its stops at the end of the rail causing physical damage before the brakes could set. While decreasing the brake set time and/or installing a larger brake was an option, it would not prevent the overrunning condition. This demonstrated the necessity to design the drive system for dynamic (regenerative) braking. From this earlier experience, a design had already been developed which we applied to the Radomiro Tomic Tripper.

The advantage of dynamic braking is safe operation in a tripper overhauling mode, as well as the ability to soft-stop the tripper. Dynamic braking occurs when an electric motor goes into an overrunning mode. The motor acts as a generator and sends power back into the VFD. If there is a means of dissipating the power generated, the motor will act as a dynamic brake. Basic VFDs are not designed to dissipate this type of regenerative power. More complicated (and more costly) VFDs are available that can dissipate the regenerative power. However, the addition of a simple low-cost item known as a chopper was added that diverted the power to a set of resistors. A chopper/resistor system consists of circuitry that senses regenerative power flowing backwards into the VFD. When this occurs, the circuitry bypasses the VFD and sends the regenerative power into the resistor bank. The resistor bank then dissipates the power. This addition allows a VFD system to operate as a dynamic brake.

At this point in the Radomiro Tomic design, we had the ability to soft-start, run in demand and regenerative modes and soft-stop the tripper. The next question was how to operate all four drives simultaneously. No two motors are exactly alike. Since all four motors were connected to the same diameter wheels through gearboxes with the same reduction ratios, the motors would be forced to run at the same speed. Standard off-the-shelf motors have slightly different speed vs. torque characteristics. This difference causes the motors to operate at different torques. In turn, this causes one motor to carry a higher load than the other motors. The common initial fix for this problem is to buy matched motors (built with similar speed vs. torque characteristics). The downfall to matched motors is finding an identical replacement motor in the future. The owner would need to buy multiple spares or replace all motors when one fails.

Due to the relatively small amount of horsepower required to drive the tripper, we were able to oversize the motors without a significant increase in cost to the tripper. The oversized motors allowed the use of standard NEMA B motors without concern for overloading any one motor. While the motors most likely run at different torques, no single motor is in an overload condition.

We now had a drive system that could run off of a single VFD/Chopper/Resistor combination, handle demand loads, handle overhauling loads, soft-start, and soft-stop the tripper.

TOUCH SCREEN CONTROL INTERFACE

While the drive system was now complete, the addition of the VFD and the necessary safety features increased the complexity of the controls. A 5" color touch screen was added as a human-machine-interface (HMI). The screen HMI was sealed and could be mounted though the door of the control enclosure thus preserving the NEMA 4 rating of the control enclosure. Its screen was an active matrix display that could easily be viewed from different angles as well as in sunlight. The HMI was more cost effective and provided a better means of communicating the tripper status to the operator than the use of lights and buttons. The use of an HMI enabled us to develop a more comprehensive and user friendly means of displaying the system information. It also provided a way to develop a bilingual control interface.

In order to make the system more intuitive the information was color-coded and broken into three screens:

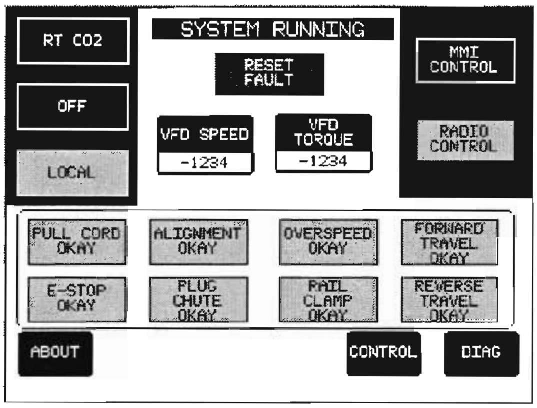

FIGURE 2 Normal operation screen

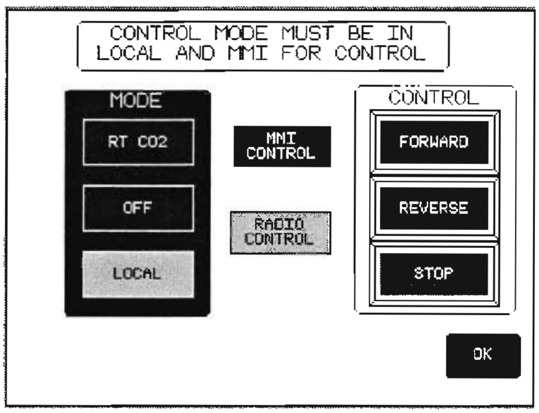

FIGURE 3 Tripper control screen

Main Tripper Operation, Tripper Control, and Tripper Diagnostics.

Touch Screens

- *Red*–information that is in "fault" condition or if a button is "off"
- *Green*–information that is "not faulted" or if a button is "on"
- *Yellow*–information that is in "warning" or "caution" condition
- *Blue*–background for status information and for active "buttons."

Screens are shown in Figures 2, 3, and 4.

HANDHELD RADIO CONTROL

A handheld radio control unit was provided with the tripper control system. The handheld radio controller works only when the system is in Local mode and is limited to the tripper's "Travel Forward," "Travel Reverse" and "Stop" functions.

To use the handheld radio controller, the operator must set the controls to Local mode at the tripper touch screen panel. Furthermore, the touch screen panel includes a key switch that the operator must activate

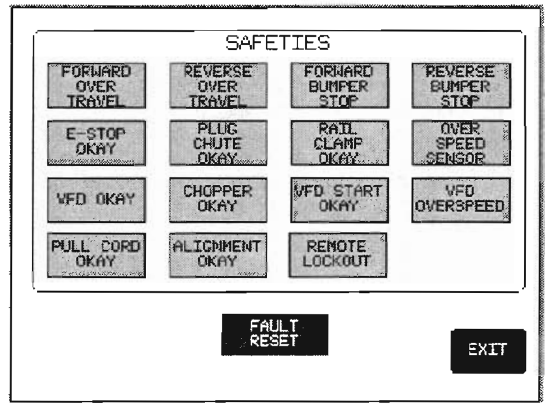

FIGURE 4 Diagnostic screen

before the handheld radio control can be used. When locked in handheld radio control mode, the tripper touch screen controls become inactive. The key switch is intended as a safety feature to protect the tripper operator while using the handheld radio control unit. Any operator using the radio control is to keep the key with them. This is to protect against the possibility of another operator taking control of the tripper from the touch screen and possibly placing the handheld remote operator in jeopardy. In addition, when locked in handheld radio control mode, a remote control room signal cannot be used to start the tripper. Again, this was intended to protect the handheld remote control operator.

STARTING/STOPPING/BRAKING

As was noted above, the VFD system provides soft starting and stopping capabilities. However, the VFD system is only active when power is applied. A fail-safe (power off) brake system is used to stop and/or hold the tripper. The braking system consists of two different types of brakes.

The first brake type is a standard spring-applied motor brake. The advantage of a motor brake is that it can be quickly applied and quickly released. This allows for a quick turnaround time when stopping and changing directions. Each of the four wheel drive motors are fitted with the motor manufacturer's standard brake. These brakes, mounted to the back of the motors, are released by an electrical signal from the control system. To ensure a fail-safe operation, a spring mechanism is used that will set and "lock" the motor shaft from turning whenever power is removed by the control system or lost due to a power failure. Unfortunately there is one disadvantage to using a motor brake system: the wheels can still slide on the rails.

The motor brake stops the motor and thus stops the wheels from turning, but the motor brake does not directly grip the rail. Therefore, a secondary parking/emergency brake is employed. This secondary brake is a hydraulically released, spring-set, fail-safe rail clamp system. The advantage to the rail clamp is that it grips the rail and holds the entire tripper from moving. The disadvantage is that there is a time lag between the release signal and the actual full release of the rail clamp. This time lag is relatively short (only a few seconds), but in order to protect against a premature start of the wheel

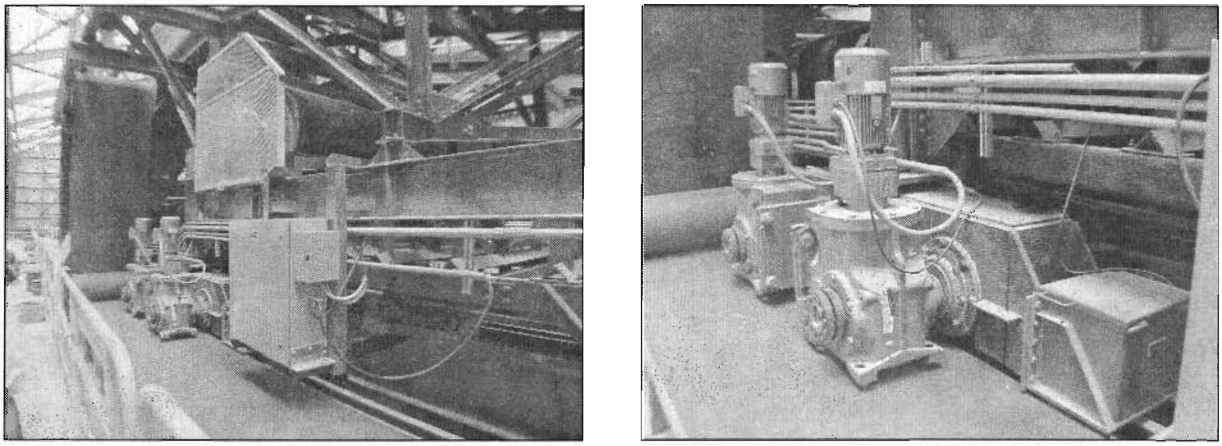

FIGURE 5 Radomiro Tomic Tripper wheel drives and rail clamp

drive motors, the rail clamp is tied into the motor starter. The rail clamp must be released and give a permissive signal prior to the motors being started. The tripper will not coast since the motor brakes are applied during the rail clamp release sequence.

Now that the soft start, soft stop, and physical brakes were established, the actual control system philosophy could be established and the logic program could be written.

Normal Start

When a run signal is received, a warning horn and light signals that the tripper is about to move. Next, the rail clamps are released and give a permissive for the drive motors to start their soft-start ramp. To ensure that the tripper doesn't coast while the motors are ramping up, the motor brakes remained engaged. The motor brakes are released when the VFD reaches a predetermined torque. The tripper is then free to move in the required direction.

Dynamic Braking

As was noted earlier, the VFD system includes a chopper/resistor combination that allows for dynamic braking of the tripper. The VFD chopper/resistor system is designed to handle a minimum of 15 stops (and 15 starts) per hour. During a soft stop, the VFD will dynamically slow the tripper to a full stop in a maximum of 3 seconds.

Normal stopping is done by dynamic braking only. Neither the motor brakes nor the rail clamps are used during dynamic braking. This allows for longer life on the brake pads.

Reverse Direction

When the tripper is traveling in one direction and the run signal is switched to the opposite direction, the tripper will go through its dynamic stop sequence. Once the drive system completes the dynamic stop sequence, the motor brakes engage to prevent coasting of the tripper. Since this is simply a reverse direction scenario, the rail clamps remain in the released position. After the tripper motor brakes engage, the control system immediately begins its start sequence for the opposite direction (with only a 10-second warning horn and light).

Normal Stop

When the tripper is traveling in one direction and the run signal is taken away (or a stop signal is received from the handheld radio control), the tripper will go through its dynamic stop sequence. Once the drive system completes the dynamic stop sequence, the motor brakes engage to prevent coasting of the tripper. Since this is a full-stop scenario, the rail clamp parking brakes engage at the same time as the tripper motor brakes.

Note: If a travel forward or reverse direction signal is received during the dynamic stop sequence, the tripper control system will respond according to the "Reverse Direction" sequence discussed above.

Emergency Stop

An emergency stop is activated by tripper bumper stop limit switches, maximum travel limit switches, tripper overspeed, emergency stop pushbuttons, tripper pull cord switches, tripper plug chute switch, a loss of signal from the rail clamp release indicating limit switch, and/or a remote lockout signal from the control room (discussed below).

When the tripper is traveling in one direction and any of these emergency stop signals are received, the tripper immediately de-energizes the drive motors, engages the motor brakes and engages the rail clamps. The dynamic stop sequence is skipped. The tripper then must be put through a mandatory reset mode that is discussed below.

SAFETY DEVICE INTERFACE

Reset Function

For safety, there is a reset function associated with the tripper local control panel. When the reset function is activated, all controls are disabled. The tripper cannot be activated (locally or remote) until the system is manually reset at the tripper local control panel touch screen. This requires the operator to go to the tripper and check on the problem before the tripper can continue operation. The following safety trips require a manual reset:

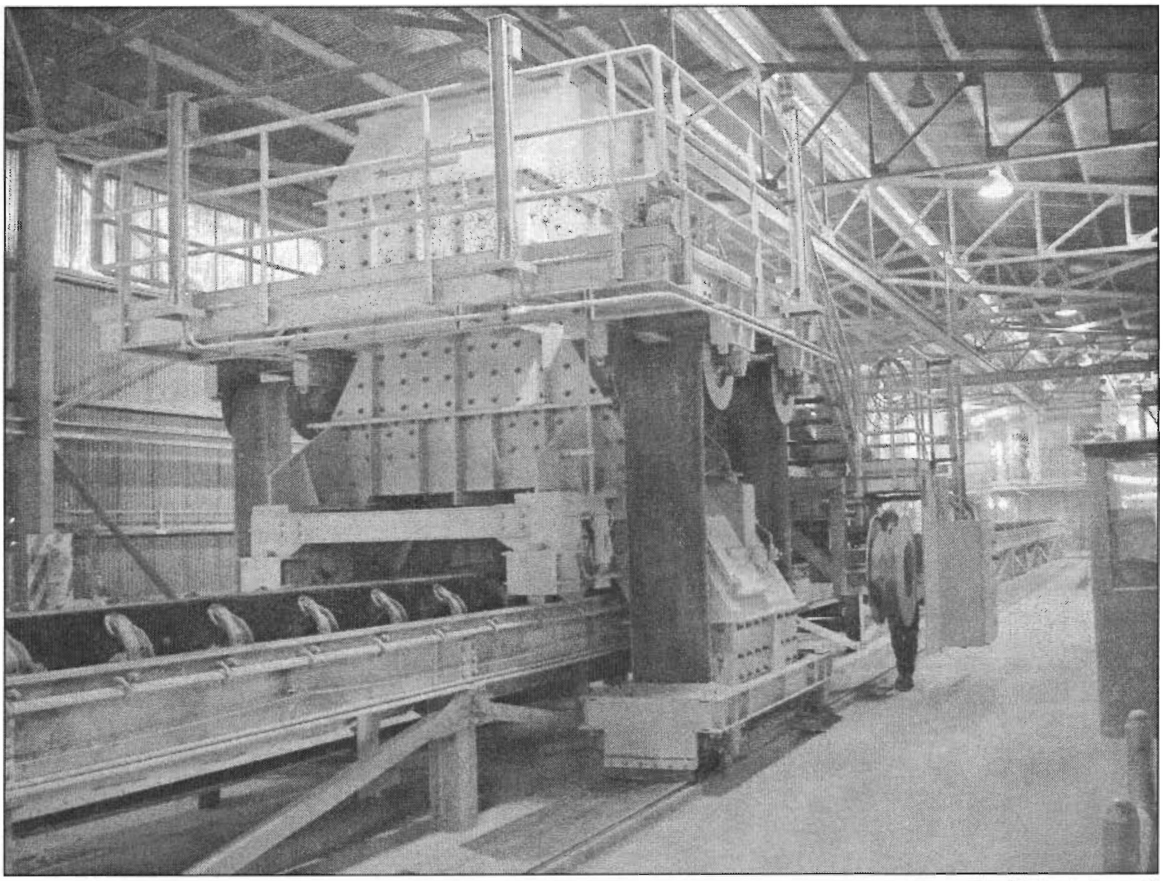

FIGURE 6 Southern Peru Copper, Toquepala Tripper during commissioning

- Bumper stop limit switches
- Maximum travel limit switches
- The tripper overspeed switch
- Emergency stop mushroom switches
- Tripper pull cord switches
- Tripper plug chute switch
- Loss of rail clamp released signal
- A remote lockout signal from the control room.

Safety Switches

- Bumper stop limit switches–These switches (mounted on the ends of the tripper) are used to shut down the tripper if a malfunction causes the tripper to contact the physical stops at the end of the rail.
- Maximum travel limit switches–These switches are mounted on the tripper and are activated by arms located on the conveyor steel. The switches are used to shut down the tripper if a malfunction causes the tripper to travel beyond the forward and reverse direction limit switches.
- The tripper overspeed switch–This switch is used to shut down the tripper and set the rail brake if a malfunction causes the tripper to go into a runaway condition.
- Emergency stop mushroom switches–These switches are mounted on either side of the tripper at the building level and onboard the tripper at each control panel. The switches can be activated by anyone to shut down the tripper.
- Tripper pull cord switches–These switches are mounted onboard the tripper along the walkway. The switches can be activated by anyone to shut down the tripper.
- Tripper plug chute switch–This switch is mounted in the tripper head chute and can shut down the tripper in the event of a plugged chute condition.
- Loss of rail clamp released signal–These switches are mounted on the rail clamps. If either rail clamp starts to close, the switch will open and the release signal will be lost. The control system will then shut down the tripper to avoid pulling against a closed brake.
- A remote lockout signal from the control room–This signal is discussed below.

Remote lockout. The control room can send a lockout signal to the tripper. This signal causes the tripper control system to shut down the wheel drive motors, set the motor brakes, set the parking brakes and lock itself out. This signal provides the control room ultimate authority over whether the tripper can be used. It also allows the control room to shut down and lock out the tripper in the event of an emergency shutdown. It is recommended that this signal be used to shut down the tripper if a conveyor pull cord switch is activated.

LOCAL/REMOTE INTERFACE

A local/remote selection screen is available on the tripper local control panel touch screen. ***For the safety of maintenance personnel, the local/remote function can be activated only at the tripper local control panel.*** When the system is set to "Local," all travel-left and travel-right signals from the control room are inoperable. When the system is set to "Remote," all travel-left and travel-right signals from the local control panel are inoperable. All safety devices operate in both modes.

CONCLUSION

The Radomiro Tomic Tripper has been in successful operation since March 2001. Based on the success of the Radomiro Tomic system, a similar control system was installed at the Southern Peru Copper, Toquepala facility in July 2002. Since they were put into full production, neither the Toquepala Tripper or the Radomiro Tomic Tripper has reported any major control, motor or VFD problems.

These successful projects demonstrate the technology available to address the wheel slippage and braking problems commonly seen on older conventional tripper designs by using a single VFD and chopper/resistor system to drive multiple motors. Furthermore, they demonstrate that multiple "off-the-shelf" standard NEMA B motors can be set up to successfully drive a tripper without any detrimental effects. Finally, they demonstrate technology that simplifies the user interface through use of touch screen controls in a dusty mining environment.

ACKNOWLEDGMENTS

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