Safety and Efficiency Improvements Utilizing Digital DC Controls

Through the implementation of digital DC controls, operations can become safer, "greener" and more reliable. Two technologies, digital DC hoist controls and digital DC magnet controls, are discussed, along with project results.

Today's global market presents pressures to achieve what sometimes seem to be mutually exclusive results: improved safety of personnel and equipment; increased throughput efficiencies; reduced energy consumption; reduced maintenance costs; increased reliability; and reduced operating costs.

Improving safety and operating efficiency is a common goal of all steel companies, and attaining any one of the above results is often a sufficient project result. It has been shown that all of the above can be achieved simultaneously through the implementation of digital DC controls. Operations can become safer, more efficient, "greener" and more reliable.

Two technologies, digital DC hoist controls and digital DC magnet controls, are discussed here, along with a sample of project results which have shown: maintenance costs reduced by 90%, throughput increased by 52%, energy consumption reduced by 80%, as well as their associated safety improvements.

Discussion

While safety itself can be justification for many projects, a project that improves safety, improves efficiencies and reduces costs is a winner with any steel company and helps improve competitiveness.

Faced with high maintenance costs and reliability issues associated with constant-potential DC crane controls, in 1995 Charlie Totten, formerly of Bethlehem Steel, sought a solution. Totten's vision was a digital DC crane control that increased reliability and decreased maintenance costs. With Totten's guidance, Cableform began development of digital DC hoist controls in 1995 and had the incalculable advantage of working on the design and testing with people who had seen many extraordinary, although rare, occurrences, which the Cableform design takes into consideration.

The designers, and the design, recognized that unexpected safety issues tend to occur when drives are subjected to conditions outside of specification that can occur infrequently and would not normally be monitored. The design, therefore, includes several monitoring devices to allow currents, voltages, temperature and other information to be conveyed to the microprocessor, which then has layers of vital information not available to the operator of the old, constant-potential systems. This information is used to limit operation, shut down operation, or warn the operators and maintenance staff when safety may be compromised.

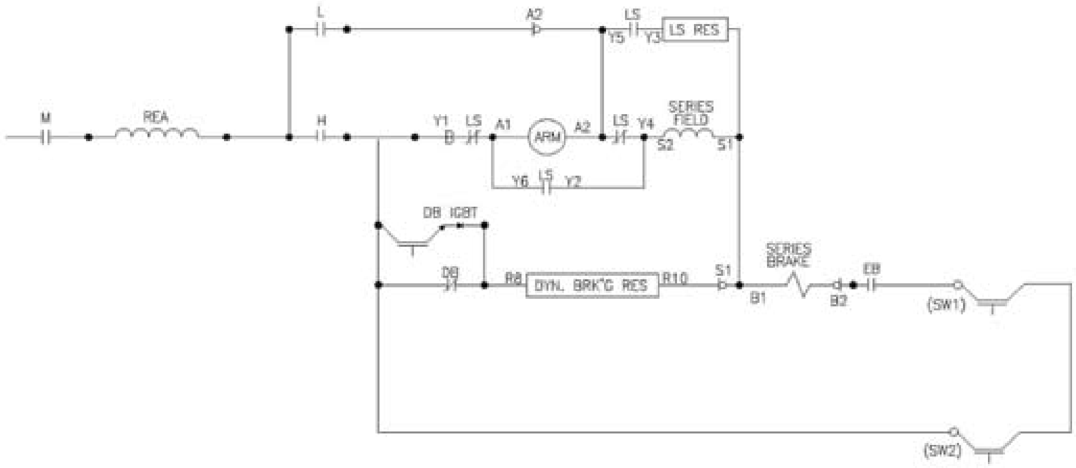
The digital DC hoist control was designed to include:

- Every safety feature present in the constant-potential contactor controls that have been in service for 70 years or more, including:
  - True series motor operation in raise.
  - True shunt motor operation in lower.
  - Series brake.
  - Power limit switch.
  - Power loss dynamic braking.
- Additional safety features available through microprocessor monitoring and control.
- Additional layers of safety protecting against uncontrolled overhauling load conditions.
- Reliability when exposed to the extreme fluctuations in the DC power supply present in steel mills.
- Reliability when exposed to the extreme vibration experienced on many older cranes.

Author

Andrew Thexton, president, Cableform Inc., Troy, Va. (andrew.thexton@cableform.com)

Figure 1



DC digital hoist power circuit.

- Reliability in the high-temperature environments of steel mills, without the need for air conditioning.

All hoist control safety features were designed-in as standard, not optional. Safety features include the following, some of which are expanded upon later:

- Power circuit and load lowering safety.
- Series brake.
- Dynamic braking (DB) loop.
- Emergency brake (EB) contactor.
- 1/2 MV^2 overhauling load protection.
- Input supply protection.
- Integral overvoltage protection (without shutting down).
- Software-based I^2T motor thermal overload protection based on Class 30 thermal curves.
- Full electrical retardation of the motor during a motor thermal overload condition.
- Full electrical retardation of the motor during controller over-temperature cutback and shutdown.
- "Slow zone" and "stop zone" inputs help prevent end-stop damage.
- Low field strength protection during lowering.

Power Circuit and Load Lowering Safety

The designers included monitoring devices and software functions to watch for failures, so that preventive measures could be taken to place the load and crane in a safe condition. Since it is also not impossible for a monitoring device to fail, relevant operational redundancy was also included.

The digital DC hoist control circuit was designed with two redundant and distinctly separate lowering power circuits: slow-speed lowering (Figure 2) and high-speed regenerative lowering (Figure 3). The only common component between the two lowering power loops is the motor. This patented design feature provides crane, load, hoist and personnel protection should a failure occur.

The low-speed loop, generally referred to as the dynamic braking (DB) loop, provides slow lowering of a load if all power is lost and the series brake fails to set. The motor armature generates into its field via a resistor and self-excites sufficiently to provide the braking action.

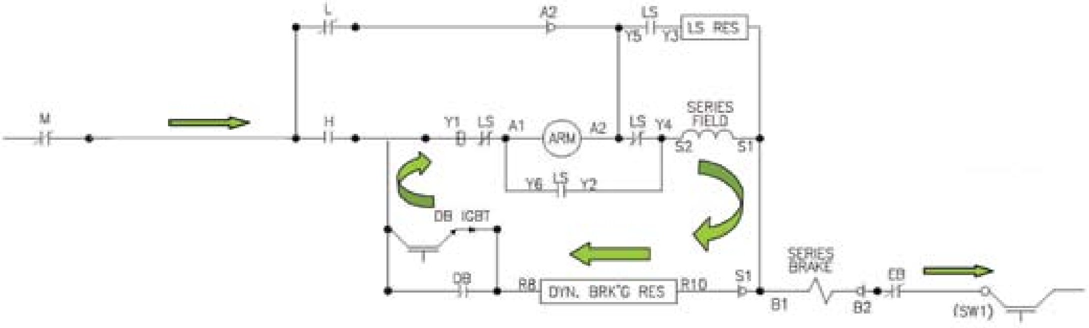
For example, should an open circuit occur in the slow-speed DB loop while operating in the slow-speed loop (Figure 2), the control of the load transitions to the regenerative lowering loop (Figure 3), effectively third speed. There is operational parameter monitoring and logic to detect such a condition, and automatic shutdown to place the load and the system in a safe condition. As additional protection, even if the detection circuits were to fail, the described transition occurs without any device switching, and the operator could shut down from a controlled third-speed condition.

Should the reverse condition occur — an open circuit in the high-speed loop (Figure 3) while operating in the high-speed loop — system monitoring detects the condition, and the microprocessor takes action to switch to the low-speed loop (Figure 2). Detection and action to transition to the low speed takes place in microseconds, IGBT switching time.

Series Brake, DB Loop and EB Contactor

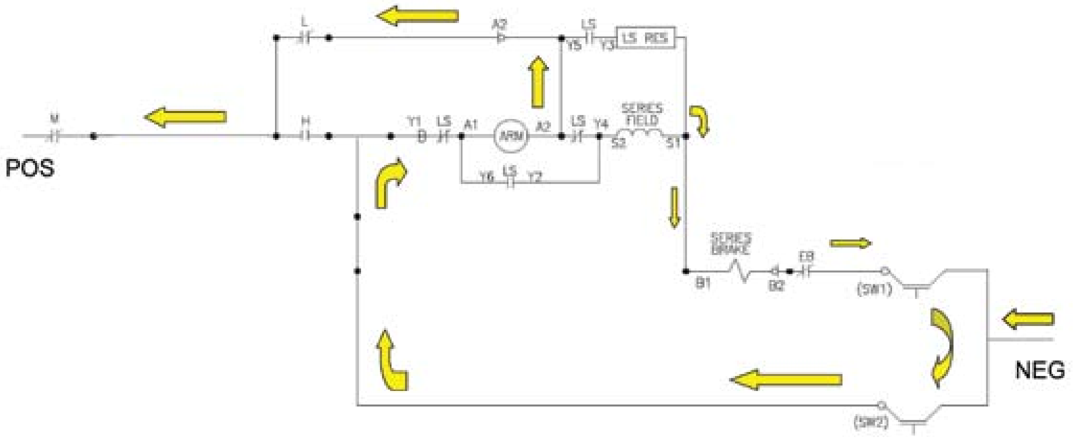
One of the safety functions of the dynamic braking loop is to provide slow-speed lowering of a load if all power is lost. The motor armature generates into its field via a resistor and self-excites sufficiently to provide braking action.

Figure 2



Digital DC hoist slow-speed lowering.

Figure 3



Digital DC hoist regenerative lowering.

Crane safety is finally dependant on actuation of the series brake, as its proper operation is called upon to secure the load.

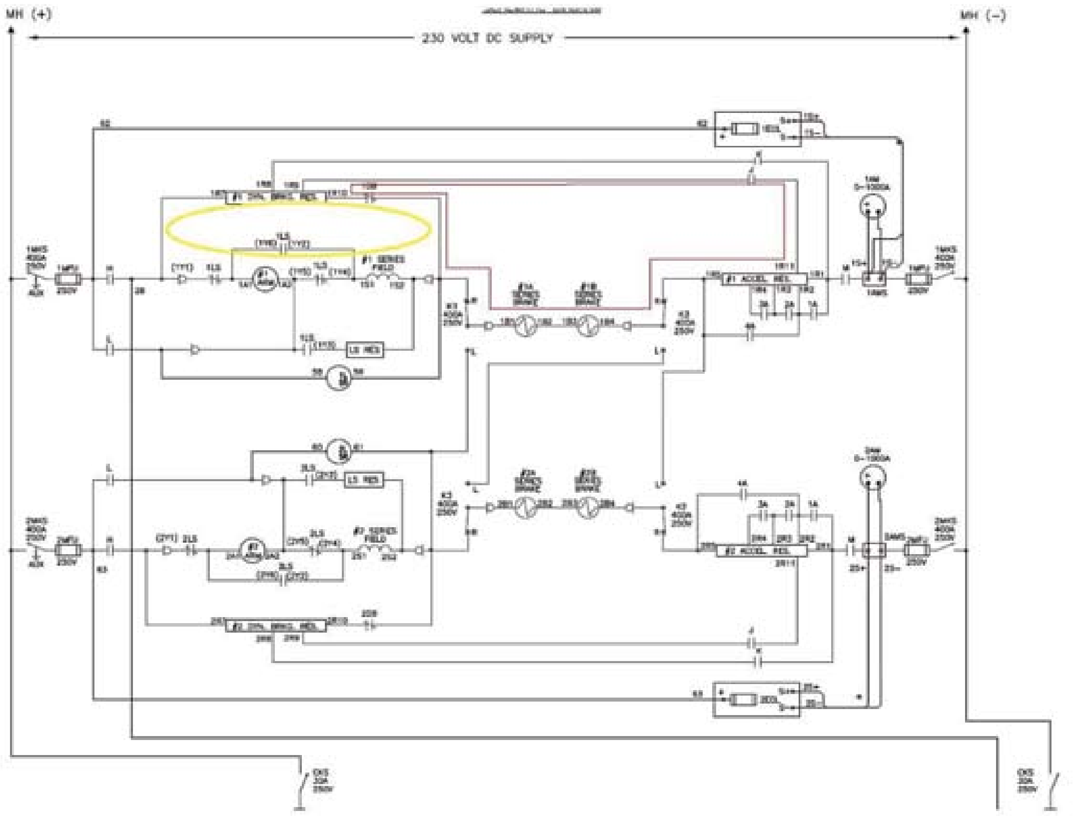
A safety problem that remains with the series brake DB loop combination is that the operation of the series brake can be jeopardized if a component failure occurs, which allows for an alternative current path, causing the series brake coil to remain energized.

In the constant-potential hoist control circuit of Figure 4, uncontrolled lowering can occur if the J contactor fails closed. This can occur upon loss of power, but more likely when the operator centers the operator control, intending to secure the load from lowering.

In the case of a J contactor failing closed, the overhauling load causes armature generation through the series field and DB resistor as designed, but current may also flow through the loop comprising the series brake, acceleration resistor and the J contactor. This alternate current path can be of sufficient magnitude to maintain the series brake coil energized and prevent the brake from setting to secure the load. Again, in this case, the load will slowly lower until the overhauling condition no longer exists, which usually occurs when the load touches the ground. For a magnet or billet, the overhauling load condition ends when the load reaches the ground. For a ladle, or other load requiring a stand, the overhauling load condition may not end until the load is on its side.

A recent example of this type of failure occurred on the ArcelorMittal Georgetown–East 140-ton crane. Analysis of the problem showed that a damaged cable at one of the resistor banks caused intermittent fault currents flowing through the J contactor that ultimately caused the J contactor tips to weld closed. The welded J contactor provided a conducting path through the brakes when the motors were acting as a generator during load descent (Figure 4). In that situation, the load would keep descending for a while, despite the fact that the operator had the crane controller in the neutral position. The situation was validated by holding the J contactor closed while lowering a full ladle and observing the ladle moving slowly down when the controller was put in neutral position after

Figure 4

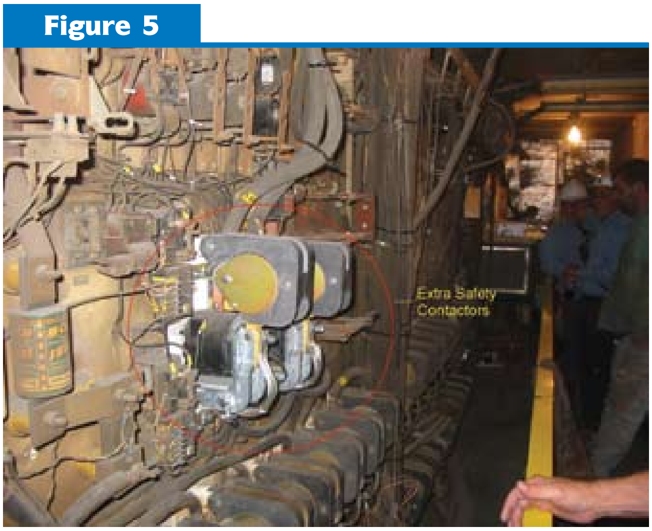


Constant potential control brake current path.

the descending position. Corrective actions included installation of normally open EB contactors connected in series with the series brakes in order to allow the crane operator to open the brakes in the unlikely event of having the J contactors welded again. Fortunately, there was no serious accident in this case.[1]

In digital DC controls, similar alternative current loops can be created upon component failure due to the presence in the circuit of regenerative diode paths. Upon component failure, these diode paths can create current loops that also allow the motor to generate into the motor field winding and the brake coil. The result of a failure mode described in "Information to Be Exchanged Prior to a Retrofit With Digital DC Controls," presented at the 2003 AIST Crane Symposium,[2] is to

Figure 5



EB contactors installed.

Figure 6

Validation testing.

allow the load to drift down extremely slowly, as described with the constant potential control, until the overhauling load condition no longer exists.

As also described in the 2003 presentation, under the right conditions, the series brake itself can operate as a generator and, in a different failure mode, can remain sufficiently excited to hold off the brake and allow the load to drift down.

In addition to the two independent current loops described earlier, Cableform digital DC hoist controls were designed to include, as standard, an emergency brake (EB) contactor in series with the series brake to ensure that the failure modes described above cannot affect the series brake action. The EB contactor is a normally open contactor connected in series with the series brake, such that a definite break in the series brake circuit is made upon loss of power, opening of the line contactor or activation of the e-stop, allowing the series brake to set. The EB contactor has minimal mechanical operations and never normally breaks a load, so is not considered to be a maintenance item.

Any DC hoist control that does not employ an EB contactor risks an uncontrolled load lowering and control architectures, which allows for failure of the DB circuit.

1/2 MV^2 Overhauling Load Protection

A hoist can be loaded with a mass greater than its rated capacity, sometimes inadvertently, sometimes under supervision, to perform an infrequent but required operation. There can be a danger to personnel and equipment caused by the overhauling load, whose momentum can exceed the rated stopping capacity of the series brake.

The kinetic energy of a load is equal to 1/2 MV^2, and the stopping power required to secure the load increases proportionally to the mass and exponentially with the lowering speed. An excessive load lowering at a high rate of speed could overcome the ability of the crane systems to safely secure the load.

1/2 MV^2 overhauling load protection effectively weighs each load as it is raised. If the weight of the load exceeds set levels, the drive will inhibit lower speed 5, or lower speeds 4 and 5, depending on the mass of the load. The effect of automatically limiting the lowering speed is to limit the lowering velocity, so that the kinetic energy of the heavy load is limited and movement of heavy loads can be accomplished without exceeding the peak ratings of the lowering system stopping capacity.

In addition to 1/2 MV^2 overhauling load protection, maximum lift current values can also be used to limit the lifting capacity of the hoist motor and prevent excessive lifts.

Digital DC Magnet Controls

Safety of magnet operation, from a control perspective, is distinctly different than the safety of crane controls. Crane control safety, whether it be travel or hoist control, generally requires that the crane be placed in a low-energy condition, which usually means securing motion of the bridge, trolley or hoist and securing power. Since magnets require power to maintain hold of their loads, unlike in the crane controls, actions are taken to maintain current flow through the magnet for as long as possible to help prevent releasing the load.

Battery backup systems can be of benefit in the right applications to allow continued suspension of magnet loads until the load can be placed on the ground. Battery backup systems can benefit both constant-potential controls, as well as digital DC controls, but the digital DC controls have properties and features that make them more effective.

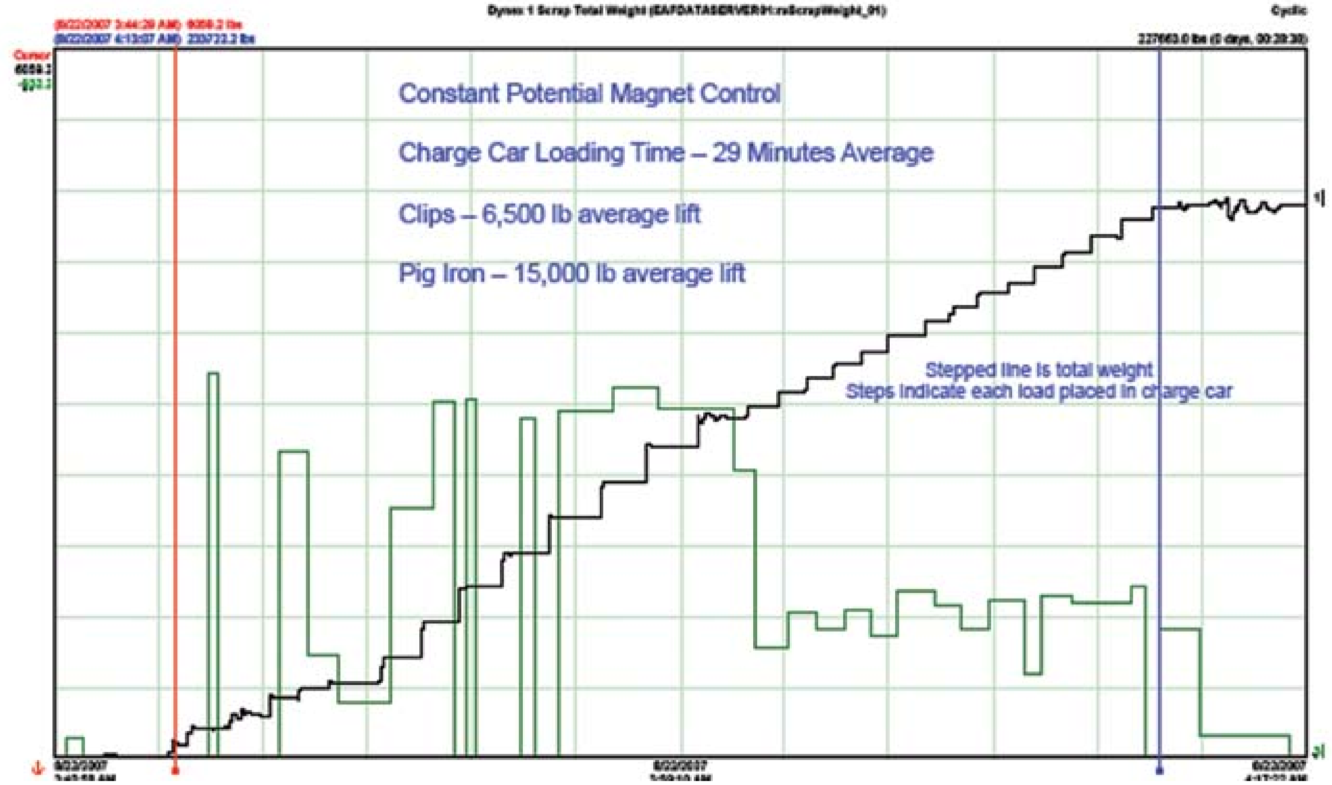
Digital DC magnet controls can require up to 80% less energy to hold a load as compared to constant-potential controls. This is achieved through the combination of PWM switching, current multiplication and reduced hold current values. The benefit here is that, for a given size of battery system, the load may be maintained for a longer period of time, utilizing the digital DC magnet control as compared to a constant-potential design.

Power loss ride-through is also an advantage of digital DC magnet controls. When power to a magnet control is interrupted — due to conductor shoe bounce, for example — the contactor coils of a constant-potential system will de-energize based on their particular discharge characteristics. When the coil currents are no longer sufficient to hold the contactors in place, the discharge load (resistor or varistor) is placed in circuit, and magnet energy is discharged.

Digital DC magnet controls have improved ability to ride through power interruptions:

- IGBTs are controlled using less energy than contactor coils.
- The capacitor bank uses stored energy to power the control power circuits.
- The magnet can be placed in a low-impedance current circulation loop so that it is not quickly discharged.
- Small amounts of stored magnet energy can be diverted into the capacitor bank to continue to provide control power for the IGBT circuits.

Figure 7



Charge car loading with constant-potential magnet control.

Safety of personnel and equipment is of paramount importance, and improvements should always be designed-in and implemented where possible. While reduced maintenance and increased throughput efficiencies were the original goals of digital DC development, safety improvements gained through the use of properly designed digital DC controls are now becoming sufficient justification for their implementation.

Efficiency Improvements Using Digital DC Controls

Given safety, it is then the efficiency improvements gained through the use of digital DC controls that improve quality, production levels and competitiveness in the global market. Mills are experiencing maintenance cost reductions up to 90%, throughput capacity increases up to 52%, and power savings of up to 80% through the application of digital DC crane and magnet controls. A few application results are discussed below.

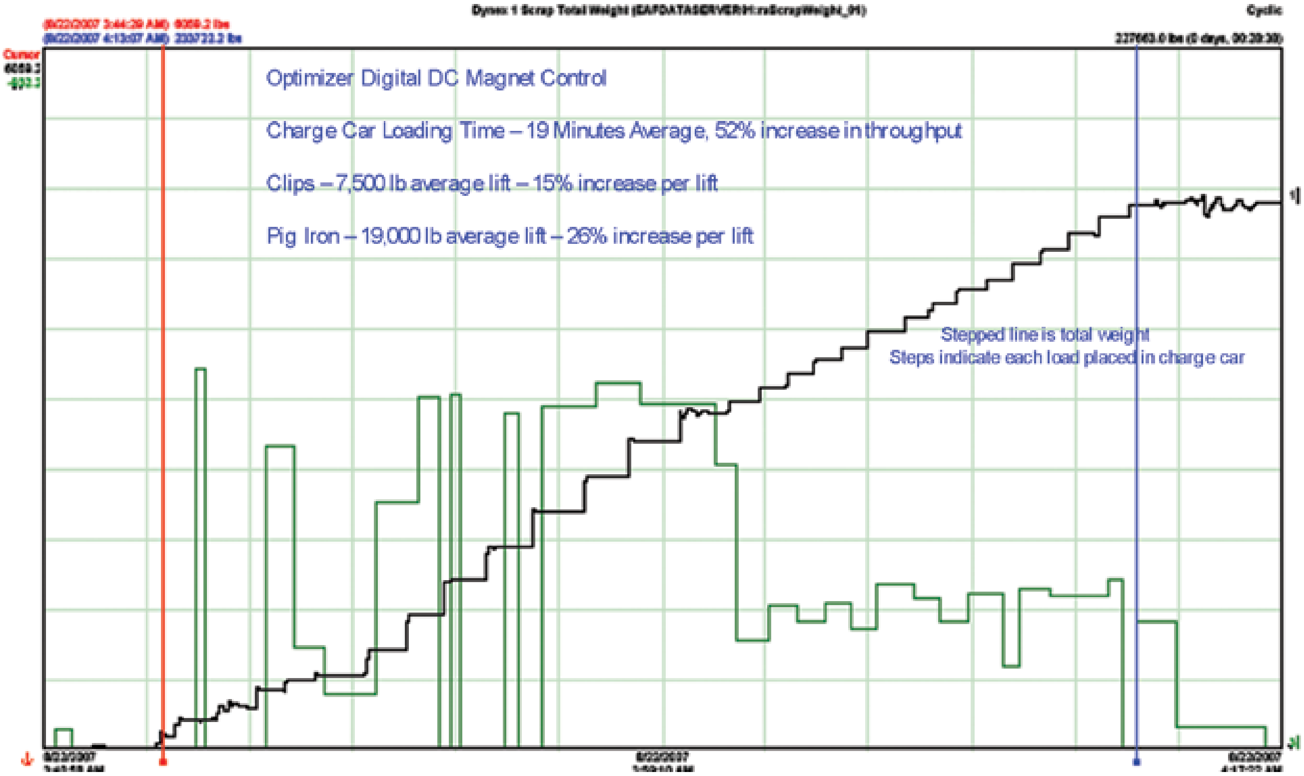
Due to their duty cycles and the environment, scrap cranes perform rigorous duty and can require a great deal of maintenance. Installation of digital DC crane and magnet controls on scrap cranes has shown up to a 90% reduction in crane maintenance costs, while also increasing throughput. One application involving a duplex 200-HP hoist, 50-HP bridge, 50-HP trolley and 350-amp magnet control experienced a 40% increase in throughput, undocumented maintenance savings and reduced energy consumption, while allowing for increased heats and steel production.

Simple installation of digital DC magnet controls has dramatically increased throughput efficiencies in scrap and plate handling applications. The data in Figures 7 and 8, provided by a mill, shows that the Optimizer solid-state magnet controls increased throughput capacity by 52%. The goal of the mill was to increase scrap throughput by 15–20% to meet the increasing demands of the mill. The 40-ton scrap crane had two rectangular magnets, each weighing 22,000 lbs. The mill was considering replacing the 22,000-lb. magnets with 33,000-lb. magnets to gain the throughput required. The drawbacks of installing larger magnets included:

- Cost.
- Additional mechanical stress on the crane.
- Having a 33-ton magnet weight on a 40-ton crane.
- Increased stress on the travel and hoist motors required to lift and move the additional 11 tons of magnet.
- The increased energy consumption requirements of both the larger magnets and the travel and hoist motors.

Installation of the two Optimizer digital DC magnet controls reduced the time required

Figure 8



Charge car loading with Optimizer digital DC magnet control.

to fill the charge car from a 29-minute average to a 19-minute average, a 53% increase in throughput capacity (Figure 9). The 52% increase in throughput capacity was gained while reducing magnet energy consumption by approximately 50%, thus reducing magnet operating temperature, without adding additional magnet mass to the crane, and was completed for approximately 80% lower cost than the alternative solution.

In this application, an additional issue was that, prior to the Optimizers being installed, the magnets would periodically pick up and de-rail the rail cars while cleaning them out. To solve this issue, a switch input to the Optimizers was installed in the operator cab to reduce the magnet current to a level that would clean out the rail cars without picking them up.

Crane modernization using digital DC controls, originally designed for the steel industry, have also benefited other industries, such as on ore bridge cranes that are unloading ships 25% faster than previously. Application

Figure 9

52% increased throughput capacity.

Figure 10

Optimizer magnet (left), clean, and constant-potential magnet (right), not clean.

at CSX, Baltimore Harbor, of 300-HP coordinated hold and close line hoist controls, quadraplex 50-HP bridge controls, duplex 200-HP trolley controls and 15-HP apron feeder controls allowed for quick and efficient unloading of ships diverted to Baltimore when Hurricane Katrina had closed the ports in New Orleans, La.

Summary

Digital DC controls were originally designed to reduce maintenance costs and increase reliability in steel mill applications. The technology was developed because Charlie Totten had the vision and the willingness to be the champion in a harsh steel mill environment — with all the temperature, dirt, vibration, reliability, production, and power supply issues common to steel mills — and it was a politically harsh environment, as change is often accepted slowly in the steel industry.

The goals of reduced maintenance and increased reliability have been met. Not only have these goals been successfully achieved in many applications, but crane safety has also been improved. Additionally, proof of the technology in steel mill environments has led to the development of additional digital DC controls in the mill environment, such as the Optimizer magnet control and digital DC motor soft-starts, which continue to improve efficiencies and make steel mills more competitive in the global economy.

Mr. Totten always referred to digital DC controls as "the future." As more mills now apply the technology, and as application of the technology is becoming standard, digital DC controls are now the present.

Acknowledgments

The author wishes to thank Charlie Totten for his vision and guidance and for being a willing champion for the development and implementation of digital DC control technology. Also, the author thanks Graham Thexton, who led the development, and all the mill personnel, engineers and technicians who have aided in the development and implementation. Additional thanks to Marcello Murta for sharing his brake failure information so that others may gain from the experience.

References

1. Murta, Marcelo G., "ArcelorMittal Georgetown–East 140-Ton Crane — Brake Failure Analysis," Georgetown, S.C., 2007.

2. Thexton, Graham S., "Information to Be Exchanged Prior to Installation of Digital DC Drives," Pittsburgh, Pa., 2003. ✦

This paper was presented at AISTech 2008 — The Iron & Steel Technology Conference and Exposition, Pittsburgh, Pa., and published in the Conference Proceedings.

Company Index — 439June