Whitepaper: Troubleshooting Mysterious Conveyor Problems

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Abstract
Long overland conveyor belts, high power conveyor belts, and downhill conveyor belts can fail for reasons that are impossible to determine by visual inspection. This paper describes a data acquisition system using strain gauges, load-cells, tachometers, and high speed data collection hardware that we developed to diagnose invisible problems in conveyors. We present real world examples that show how our system helps us solve problems in wound rotor motors, brake control systems, take-ups, and magnetic couplings. These case studies illustrate the diverse collection of invisible conveyor problems our system detects.

Keywords
Sensors — Data Acquisition — Conveyor Belts — Wound Rotor Motors — Brake Hydraulics — Magnetic Couplings — Control Systems

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Introduction

In large conveyor systems, motors, brakes, and holdbacks can generate momentary torque high enough to break couplings or reducers. Rapidly increasing or decreasing torques can also generate dynamic shockwaves in the belt that are strong enough to break: pulleys, structures, belt splices, or cause issues in vertical and horizontal curves.

Most conveyor failure investigations consist of: a visual inspection, a basic engineering design review, and a review of the historical trends stored in the site's data historian. When shockwaves caused the event, this approach often fails uncover the root cause of the failure. The sensors necessary to detect shockwaves are rarely installed on conveyors, and when they are, the data historians employed in industry today almost never record these sensors' output frequently enough to detect the shockwave.

When Conveyor Dynamics, Inc. (CDI) suspects a dynamic torque or shockwave event caused a conveyor to fail, we install a high-speed data acquisition (DAQ) system and temporary instrumentation that we developed to record rapidly changing torque in a conveyor's drivetrain. Our system allows us to determine how to modify a conveyor's mechanical design and/or control system to eliminate damaging shockwaves and extend to many years the life, of equipment that previously to failed in months.

1. Issues with Typical Conveyor Instrumentation

Motors, brakes, and holdbacks can all change the torque in the drivetrain in milliseconds. A motor in particular, can subject the drivetrain to 2 – 3 times its nameplate torque in a few milliseconds if the motor is not properly controlled. Most data historians deployed in the field, like the popular PI System from OSIsoft, record the Programmable Logic Controller (PLC) inputs every 2-5 seconds in a temporary buffer, and to save space after a few hours, the systems usually resample data, saving only one sample every few minutes in a persistent database. Even a 2 second sample rate is much too slow to detect rapidly changing drivetrain torque or shockwaves moving at the speed of sound. To get a clear picture of these dynamics, a sample time no slower than 10ms is required.

Very few conveyors have sensors installed to measure drive shaft torque. Motor current is commonly measured, but this parameter is tricky to convert to torque when the speed of the conveyor is low or the system is lightly loaded. Motor current has no relation to brake and holdback torque, which are also important sources of shockwaves. Brake torque can be inferred from brake pressure sensors (when they are present), but this requires assumptions about pad wear, brake fade, and minimum pressure to release the brakes that may or may not be true. In our experience, the best way to detect unanticipated torques in the drivetrain is to measure the shaft torque directly using strain gauges.

2. Detecting Conveyor Dynamics

To measure shaft torque, CDI installs temporary strain gauges on the pulley shafts, and convert the strain measurements to shaft torque.

Our strain gauges are driven by a strain gauge amplifier/transmitter mounted to the output shaft of the reducer (Figure 1) that transmits the strain and temperature to a receiver connected to a laptop computer.

Figure 1. Strain gauge amplifier and transmitter

In addition to shaft torque, we sometimes need to record brake proximity switches, brake pressures, the conveyor start command, take-up winch tension, take-up position, belt speed, belt side travel, wound rotor motor resistor contactor proximity switches, or accelerometer output. Radio transmitters are not required to collect these additional signals and we typically hardwire our DAQ box to the instruments measuring these values, or to a PLC output cards. Many conveyors do not have the instrumentation needed to measure belt speed, side travel, take-up position, or take-up tension. When required, we install the temporary sensors shown in Figure 2 to obtain these measurements. CDI typically configures our DAQ boxes to sample at a rate of 64 Hz, but on occasion we have sampled a system at 1000 Hz.

3. Real World Results

3.1 General

To illustrate the kinds of problems our instrumentation can detect we have chosen four examples from the real world. It is very uncommon for us to find the same problem in two different conveyors. These examples show the wide range of unusual problems our instrumentation can detect.

3.2 Wound Rotor Motor Torque Spikes Failing Reducers

Wound rotor motors are a type of induction motor where the rotor windings are connected to external resistors via slip rings. Increasing the external resistance reduces the motor torque. To achieve a smooth start, each motor is connected to a binary stack of resistors connected in series. Each individual resistor in the stack is typically connected in parallel with a contactor. Closing several of the contactors shorts their resistors, effectively removing them from the stack while allowing the unshorted resistors to reduce the motor torque. A typical stack with different 8 resistors can be combined in $2^8 = 256$ different resistance levels.

As a round rotor motor accelerates, its rpm increases and the resistance required to achieve a given torque drops. Figure 3 shows the data the DAQ system collected from strain gauges when three wound rotor motors were used to start a conveyor. At a given level of resistance the torque clearly drops as the motor accelerates until the next "step" down in resistance restores the torque. The speed of the torque drop increases as the motor nears synchronous speed. Figure 4 shows that several of the step downs in resistance are creating large spikes in torque.

In many of the resistance steps, some contactors open and others close. When closing contactors do so before opening contactors open the resistance momentarily drops causing the motor torque to spike up. The specification for the contactors installed at this site stated that they close in 40ms and open in 100ms. The original designers delayed the contact close command by 100ms relative to the contactor open command hoping to avoid momentary low resistances. Figure 4 show the moment the PLC transmitted contactor state change commands, the moment the contactor proxy switches detected state changes, and the motor torque our system recorded during this resistance step change. We used different data loggers to record motor torque and contactor states so the time synchronization between the torque and contactor plots is not exact. The data shows that after 10 years of use the contactors needed 250ms to open, but still closed in 40ms. CDI adjusted the resistor timing so that the contactor close signal was 500ms after the contactor open signal. This eliminated the torque spikes. No reducers have failed in the 8 years since we completed the change. Diagnosing this problem required high frequency sampling of the contactor proxy switches and shaft torque measurement, neither of which were available in the conveyor as originally installed.

3.3 Slow Brakes

Figure 5 shows an intended motor stop on a large downhill conveyor. At about 25% speed the motors tripped, and the control system requested a brake stop. The strain gauges proved that for 15 seconds, Brake C did not apply, Brake B was at 39% motor torque, and Brake A was 82% motor torque. After 15 seconds, the control system determined that the conveyor was accelerating and requested a brake dump, rapidly applying the full brake torque on all three brakes (150%-200% motor torque). This data proved that the brake logic and/or hydraulics were unacceptable and needed to be replaced.

While it is true that the PLC can monitor and record brake pressure, the link between changes in brake pressure and torque is not linear. The reduction in pressure while the brake calipers close the air gap between the brake pad and the brake disk results in no increase in torque. The exact pressure required for the pads to touch the disk without applying torque depends on the pad wear and spring extension and is different for each brake. During long stops, the disk and pad temperature rise substantially and as their temperatures rise, the coefficient of friction between the brake pads and disk changes. This in turn, changes the torque a given pressure produces resulting in "brake fade". The effect is particular

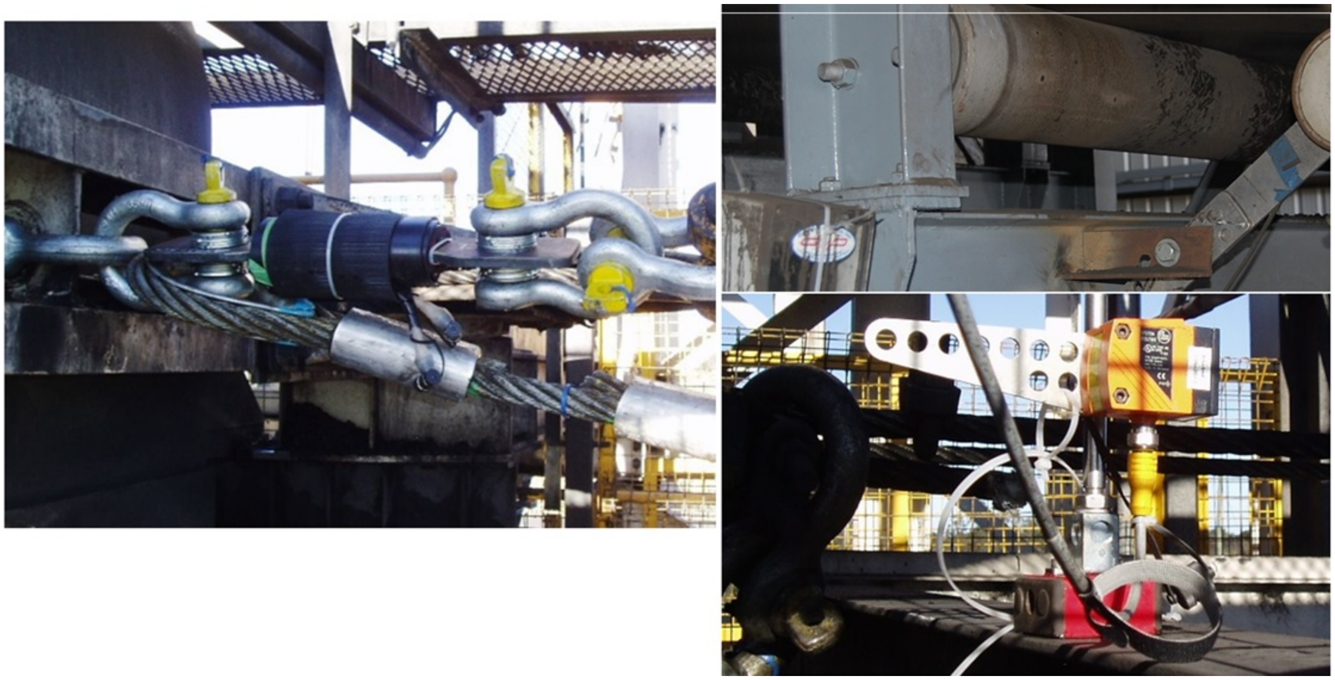

Figure 2. Temporary Take-up Tension, Belt Speed, and Take-up position measurement

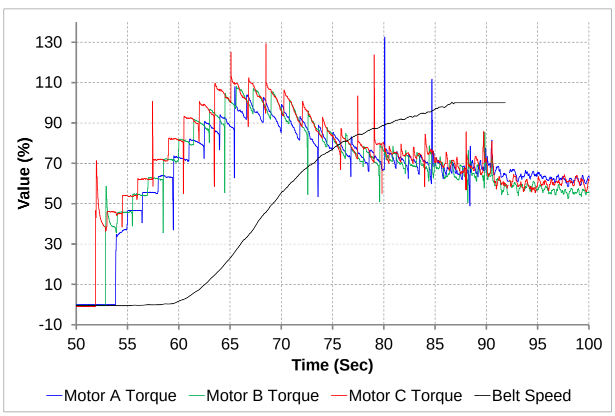

Figure 3. Motor torque and belt speed during a conveyor start before CDI tuning

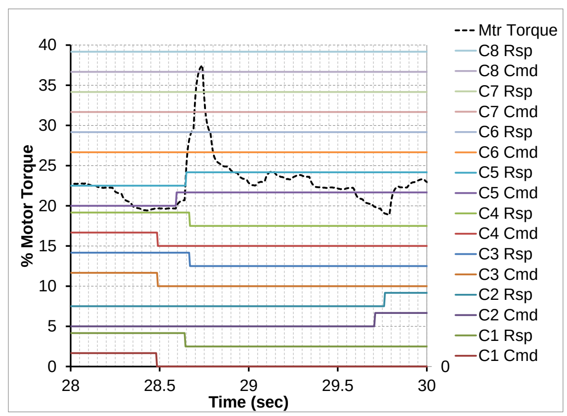

Figure 4. Contactor Command-Response Times during an empty start. “C1 Cmd” = “Contactor 1 Command”, “C1 Rsp” = “Contactor 1 Response”. “Mtr Torque” = “Motor Torque”. Contactor signal drops when it opens (adding resistance), and rises when it closes (removing resistance)

pronounced in long downhill conveyor stops. Only strain gauges can measure the actual torque brakes apply and how quickly they apply this torque.

3.4 Take-up Hysteresis

During one of our site inspections we noticed that the take-up sheaves guiding the take-up cable from a horizontal take-up to a gravity counterweight tower were too small. Replacing these sheaves with the required sheave size (Figure 6) was a costly change. CDI inserted a load cell between the take-up trolley and the cable and demonstrated that increasing the existing sheaves prevented the take-up counterweight from rising after the conveyor stopped which dramatically increased the tension in the belt. Increasing the sheave diameter freed the counterweight and allowed it to maintain constant belt tension at the take-up (Figure 7).

3.5 High Torque in Magnetic Couplings

Recently, magnetic couplings utilizing rare earth magnets to transfer torque from the motor to the reducer have been growing in popularity. CDI has encountered several conveyors

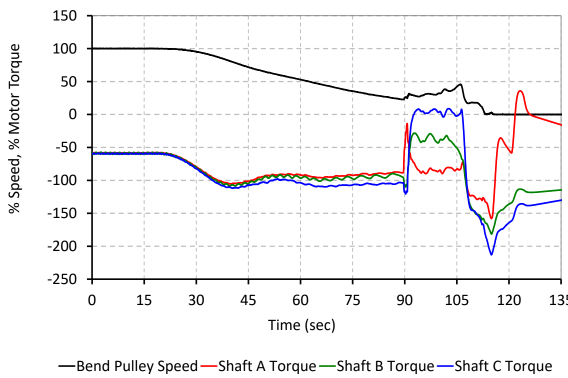

Figure 5. Shaft torque and speed during an aborted motor stop

Figure 6. Old and new take-up sheaves

where site personnel replaced fluid couplings with magnetic couplings.

Unfortunately, magnetic couplings subject reducers to much higher torque spikes than properly filled fluid couplings. Magnetic couplings often subject reducers to more than 200% motor torque during the start.

The shape of magnetic coupling torque vs. slip curves is very similar to the shape of induction motor torque vs. slip curves. However, while induction motors start at 100% slip and converge on 1-2% slip at full speed, a fixed gap magnetic coupling starts at 0% slip and cannot allow more than or 1-3% slip at any time. Since fixed air gap magnetic couplings do not allow substantial slip, they effectively create an across-the-line start that transmits the “breakdown torque” of the induction motor to the conveyor.

Induction motor breakdown torque is often 200% - 300% of motor nameplate. Strain gauge measured starting torque vs time data from a conveyor with magnetic couplings is shown in Figure 8. The magnetic couplings allowed the motor to transmit 190% torque to the conveyor for 6 seconds. The only reason the couplings did not transmit more torque is

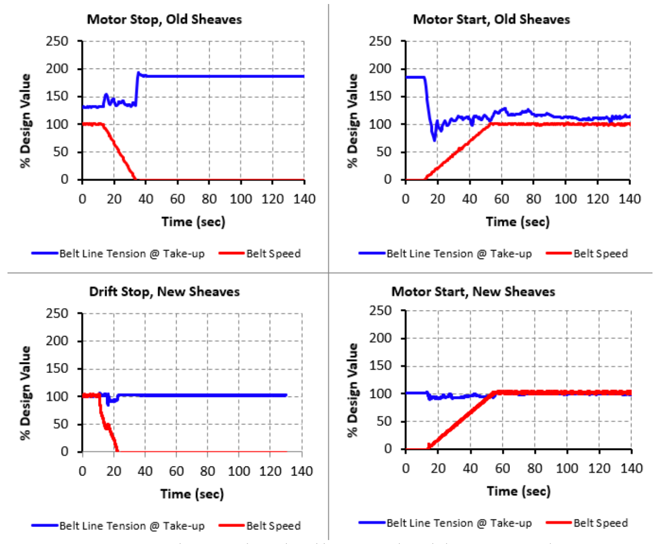

Figure 7. Take-up loadcell record, old vs new sheaves

that the magnetic coupling reached its own breakdown torque before the induction motor did. From a conveyor shockwave perspective, magnetic coupling starts are no different from across-the-line starts.

Ideally, the magnetic coupling air gap would dynamically change to avoid transmitting the induction motor breakdown torque to the conveyor. Unfortunately, with today’s technology, adjustable air gap magnetic couplings cannot tolerate high slip for a long enough time to start a high inertia conveyor. The slip on a magnetic couplings must be low because rare earth magnets begin to temporarily demagnetize above 100 degs C and permanently demagnetize above about 170 degs C. We have not seen any examples of magnetic couplings with sufficient cooling capacity to start a large conveyor without transmitting the breakdown torque of either the coupling or the motor to the conveyor.

Figure 8. Conveyor Start Magnetic High- Speed Couplings

3.6 Conclusion

Strain gauges, load cells, and a high frequency data acquisition equipment reveal many issues in conveyors that are not apparent in data typically stored in a SCADA historian. They reveal the idiosyncratic behavior in each manufacturer's product, provide better insight into how to tune, control, and model conveyor components. CDI's data acquisition system allows us to demonstrate why a particular conveyor component repeatedly fails when all the parties involved in the design say the design is correct.