Case study: correcting control problems on Essroc's multidrive station, horizontally curved conveyor

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Abstract

Controlling long overland conveyors with multiple drive stations is a complex problem. The methods for controlling these belts in a steady state are well-covered in existing literature, but a discussion of starting and stopping strategies is absent. This paper outlines different control strategies for starting, stopping and running conveyors with multiple drive stations. To illustrate the benefits of applying the methods described in this paper, the authors show how their adoption corrected many of the control system problems at Essroc Cement's overland conveyor, which features three drive stations separated from each other by long lengths of continuous conveyor belt.

Key words: Conveyor belt, Overland conveyor belt, Optimization

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Introduction

In November 2005, Essroc Cement, part of the Italcementi Group, commissioned a long overland conveyor at its Nazareth plant in Pennsylvania. This conveyor, tagged CV-105, was designed to transport 907 t/h (1,000 stph) of limestone from the quarry to the kiln, and 363 t/h (400 stph) of hot clinker (at 150° C) back from the kiln to a handling facility about halfway back.

Conveyor CV-105 is 2,738 m long. It gains 57 m of elevation in the first 390 m, then is mostly flat for the remaining 2,348 m (Fig. 1). After the limestone is discharged at the head pulley, hot clinker is loaded onto the return side of the belt. This clinker can be discharged at one of two locations.

The conveyor is powered by six motors at three different drive locations (Fig. 2). Two motors are located at a booster station 479 m from the tail, three motors are located at the head station and one motor is located on the return side at the second clinker discharge pulley, 2,263 m away from the head (Fig. 1). The design of the conveyor is further complicated by nine horizontal curves (Fig. 3), seven of which have a horizontal radius of 400 m (Fig. 4).

By early 2006, it was clear that conveyor CV-105 and its drive controls were not functioning properly. Large speed and motor torque oscillations were common, which regularly tripped the conveyor. The conveyor was usually very difficult to start, and large belt tension variations on the carry and the return sides resulted in significant side travel of the belt in the horizontally curved sections, which resulted in extensive belt edge damage.

The original designers of the system hired the manufacturer of the drives and programmable logic controller (PLC) to correct the problems. After nine months of site work, the manufacturer's experts got the conveyor to a fairly stable condition. However, failures were not uncommon. The belt in the tail turnover would occasionally buckle and flip over, causing days of downtime, and there were many splice failures and at least one take-up cable failure. This suggested that, under some conditions, the belt tension fell too low, allowing the belt to buckle in the turnover, while at other times the belt tension climbed too high, damaging the belt splices and breaking the cable. Furthermore, the conveyor was often difficult to start when the temperature changed, which required additional tuning of the drives.

Following a splice failure in October 2008, Essroc commissioned Conveyor Dynamics Inc. (CDI) to review the conveyor design and conduct a site survey to see if anything could be done to improve the reliability of the conveyor. Since 2008, CDI has performed a number of site surveys, recommended a number of mechanical design changes, and completely rewritten the control software for the drives and the conveyor. The

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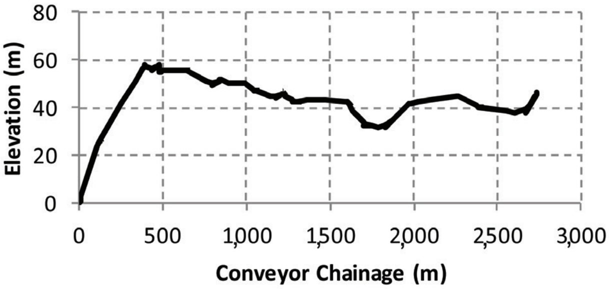

Figure 1 — Conveyor elevation.

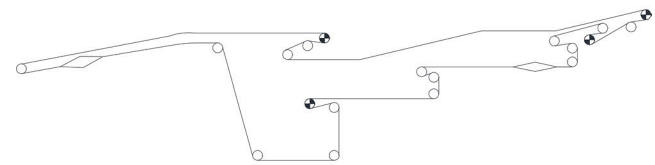

Figure 2 — Pulley location sketch.

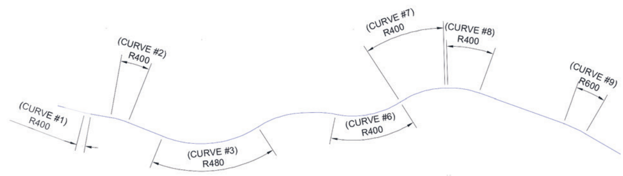

Figure 3 — Conveyor plan.

Figure 4 — 400-m horizontal curve.

focus of this article is on the significant improvements achieved by CDI's control system. Significant improvements were also achieved when the mechanical system was modified, and these improvements will be the focus of a future article.

Standard approaches to intermediate booster drive torque control for steady-state operation

The control system that the drive manufacturer installed at Essroc set a constant load-sharing ratio between the head and the two booster stations, independent of the conveyor loading or of the location of the material on the belt. The problem with this control scheme has been known for quite some time and is described in Bahke (1982). While the motors' torques were shared reasonably well when the conveyor was loaded over its complete length, this control scheme created unnecessarily large tensions in empty sections of belt as the material moved through the belt (during conveyor loading and unloading). This resulted in large, and damaging, levels of side travel in horizontally curved sections (Fig. 5).

The control of conveyors with intermediate booster drives is always a complicated issue, requiring specialized drive control algorithms similar to the control systems designed by CDI for the Zisco (Nordell, 1997) and Curragh (Steven, 2008) conveyors, or by others including Kellis and Azhar (1998). The absence of side-guide rollers at Essroc made proper torque control and belt tension management even more critical for the prevention of excessive side travel.

CDI's approach to booster station control, in general, is to independently control the drive torque at each station. Each drive station should only provide the torque required to pull the portion of the belt and material directly upstream of its location, and all drive stations should act independently of one another, except during starting and stopping sequences (Cornet, 2002).

For nonregenerative conveyors, the best way to achieve this decoupling between drive stations is to control the head drives with a normal speed-control loop, and control the booster drives in one of two ways: (1) with tension-control loops using load cells to measure the belt tension on the downstream side of the booster stations or (2) instruct the booster to produce a fixed torque at all times. The first method effectively creates "virtual" take-up after each booster station, decoupling them from each other and from the head drive station, and allows the booster to increase its torque to compensate for elevated belt tensions created by the increased load. The second method is useful when the belt between the take-up and the booster is always empty, so that the load the booster is responsible for pulling is fixed. Often, the second method works well for return side booster drives; however, in the case of CV-105, the return side is loaded with clinker, so the first method is required.

The design, parameterization and implementation of such controls is not trivial, as the wrong algorithms or the wrong parameters can easily create torque oscillations between drive stations and result in unstable conditions (Nordell, 1997). It requires the control engineer to have a good understanding of the tension wave mechanics of the belt itself, as well as a good understanding of the various control loops available in modern drives. However, when properly designed and tuned, this type of control is extremely effective at belt tension management, very stable, and very safe for the belt.

It should be noted that a load cell was already installed at the carry-side booster drive station. It seems that the original system designers envisioned a similar drive control methodology for the carry-side booster drive, and may have assumed that the return side could be controlled according to Method 2, since the clinker load is light. Possibly, they were unable to tune their controls well enough to prevent unstable speed oscillations. After nine months of testing, they settled on a simple, fixed ratio, load-sharing scheme, where all motors try to match a fixed ratio of the head drive torque. This is a method typically employed for controlling machines like pumps or automobile assembly chain conveyors that do not have large changing loads and inertias.

Problems with loadsharing between the head drive and intermediate booster drives. As Bahke pointed out in his

Figure 5 — Edge damage caused by excessive side travel in horizontal curves.

1982 paper, a fixed-ratio load sharing scheme is not suited for conveyors like CV-105. Unfortunately, this is the scheme the original designers of the Essroc conveyor installed. To illustrate the connection between the fixed ratio load-sharing scheme and the damage to the belt (Fig. 5), CDI simulated CV-105 using a model that was calibrated with the actual motor torques and tensions recorded in the field. This gave an accurate picture of the tensions in the belt for various load scenarios, and showed how these tensions would change if the control system were improved.

When a fixed-ratio load-sharing scheme is adopted, Fig. 6a shows the tension distribution when limestone is loaded on the belt between the tail and the carry-side booster station, and clinker is loaded on the return side of the belt. Note that under this loading condition, the belt is empty between the carry-side booster station and the head. Under the this control scheme, the head drives still delivered the bulk of the required torque, even though the belt was empty between the carry-side booster and the head. This effectively raised the belt tension in all the horizontal curves near the carry-side booster station, causing excessive side travel of the empty belt in these sections. Without side-guide rollers, the high belt tensions lifted the belt all the way into the structure, which resulted in extensive damage to the edges of the belt.

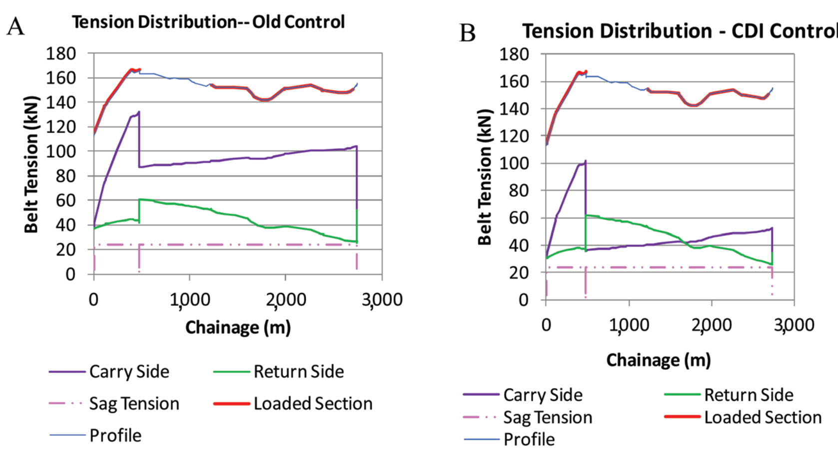

Figure 6 — BeltStat-predicted tension distribution for the original and the new (CDI) drive control schemes, with limestone loaded between the quarry and the carry-side booster station, and clinker loaded on the return side.

Figure 6b shows how the tension distribution would look if a tension-control algorithm tried to hold the tension just after the booster drive constant, increased the torque of the carry-side booster drives and reducing the torque of the head drives, resulting in significantly lower tension in the empty belt sections and in a much better, and more logical, tension distribution in the conveyor.

Similarly, Fig. 7a shows the tension distribution for a fixed-ratio load-sharing scheme when limestone is loaded on the belt between the carry-side booster station and the head, but not before, and clinker is loaded on the return side of the belt. Under the old control scheme, the carry-side booster drives load shared to the head station drives and provided a significant amount of torque, even though there was no material to lift out of the pit. This resulted in very low belt tensions after the booster station, which resulted in high belt sag and potential pulley slip.

Figure 7b shows how the tension distribution for this loading condition would look if the tension-control algorithm were implemented, eliminating the low tension problem after the booster drive station and holding the tension stable.

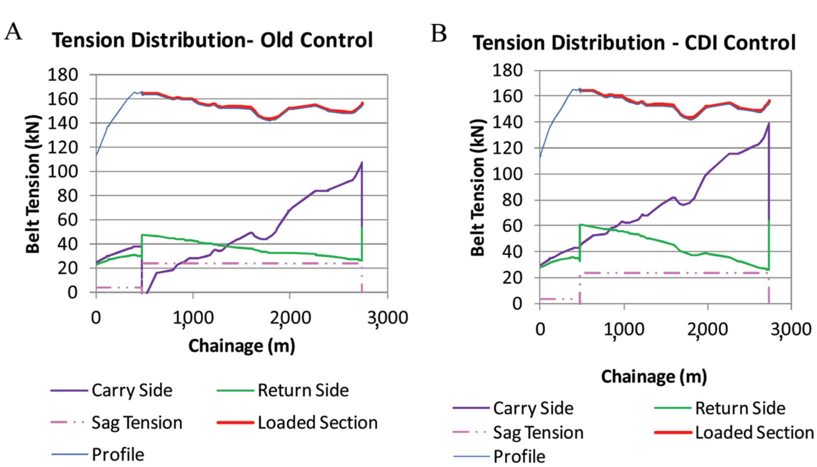

Figure 7 — BeltStat-predicted tension distribution for the original and the new (CDI) drive control schemes, with limestone loaded between the carry-side booster station and the head, and clinker loaded on the return side.

Starting and stopping controls

With a properly tuned controller, the torque control by load cell works well when the conveyor is already running. However, this method does not work well when the control is starting and stopping, because large, fast-moving tension waves are likely to be amplified by the drive trying to hold the tension constant. There is not a lot of literature published on starting

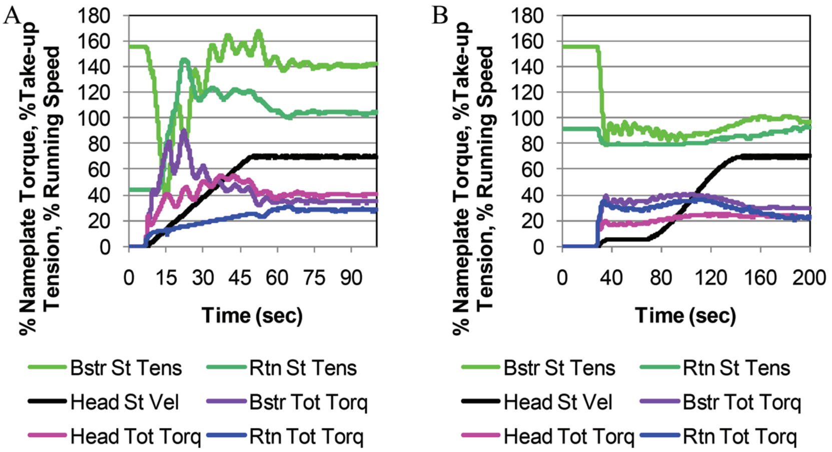

Figure 8 — Recorded motor torques and belt tensions after the booster drives (at the load cell locations) during a conveyor start fully loaded (A) before and (B) after installation of the new CDI drive controls.

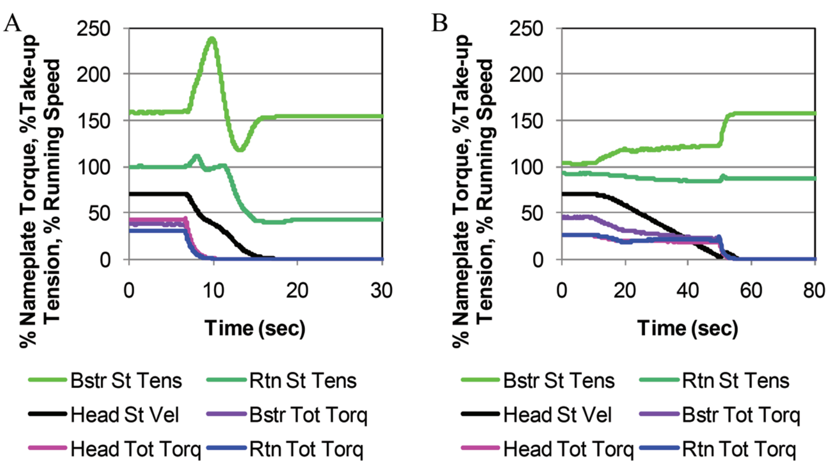

Figure 9 — Recorded motor torques and belt tensions after the booster drives (at the load cell locations) during a motor stop fully loaded (A) before and (B) after installation of the new CDI drive controls.

and stopping booster-controlled conveyors, and the authors of this paper believe this is where many designers run into trouble. When starting and stopping conveyors using drives, CDI recommends that all drives operate primarily in speed control, with load cells and/or torque limits used only to avoid low and high tension events.

In the original Essroc starting control system, some of the boosters tried to loadshare, and some of the boosters started on preset torque ramps. This caused large torque oscillations and could lead to unstable behavior, because boosters can provide too much or too little torque to keep the conveyor on the desired speed ramp.

Tests performed onsite before and after installation of the new CDI control system confirmed this result. The following recordings show the motor torque at each drive station and the belt tension after each booster drive during fully loaded conveyor starts and motor stops. The belt tension was recorded by two load cells mounted under two pulleys located on the low-tension side of the drives.

Figure 8 shows the response of the conveyor during a start using the original control and the CDI control. The original control scheme generated large fluctuations in motor torque and huge swings in belt tension (high and low). The belt tensions are nearly constant and the motor torques are more stable with the new CDI control scheme.

Figure 9 shows the response of the conveyor during a motor-stop using the original control and the CDI control. Again, the original control scheme generated large fluctuations in belt tension (both high and low). No large tension swings were observed with the new CDI control scheme.

Dynamic behavior of conveyor during emergency stops

Although mechanical recommendations are not the focus of this paper, the authors think it is appropriate to include a discussion of the changes that were required to ensure the CV-105 safely stopped when it lost power.

CDI modeled CV-105 in a power loss emergency stop with our proprietary BeltFlex code (Nordell and Ciozda, 1984) and found a serious tension problem under some loading conditions. As the conveyor was originally designed, the worst case occurred when limestone was loaded between the tail and the carry-side booster station, and clinker was loaded on the return side of the belt. In the case when the motor tripped, the limestone on the incline part of the conveyor (out of the pit) slowed down quickly, while the inertia of the clinker on the

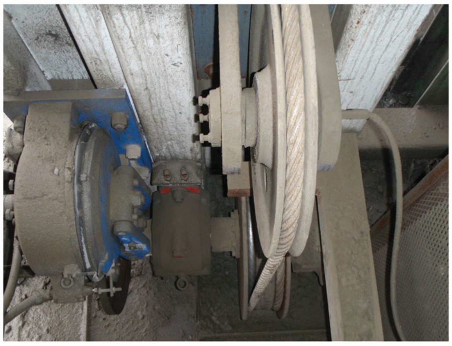

Figure 10 — Capstan take-up brake.

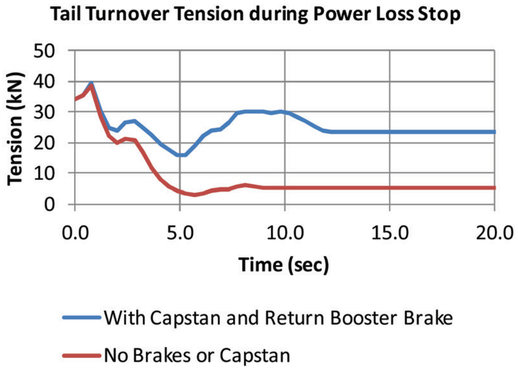

Figure 11 — Simulated emergency stop with and without the capstan brake and the return-side booster brake. In this example, limestone is loaded from the tail to the carry-side booster drive and clinker is loaded on the return side of the conveyor. Without the brakes, the tension at the tail drops below 3.2 kN. With the brakes installed, the tension stays above 16 kN.

return side of the conveyor caused the belt in this section to slow down relatively slowly. This resulted in low belt tension in the tail section that could lead to potential belt buckling in the tail turnover (Essroc reported that on one occasion the tail turnover buckled and folded in half on the tail pulley, causing a lot of downtime).

Since this condition happens when the motors trip, it is a mechanical design problem that cannot be fixed through controls and requires a mechanical solution.

Part of the solution applied by CDI was to install a capstan brake on the take-up (Fig. 10). A capstan brake is installed on the take-up reeving and, when applied, increases the take-up resistance to motion, therefore increasing the effective take-up tension. In this case, a spring-applied, electrically released brake was selected to ensure application in case of power failure. The capstan brake is kept released at all times during operation, and only engages in the case of motor trip or power failure.

The capstan brake significantly improved the tension distribution during emergency stops, but not enough to completely eliminate the low tension problem in the tail turnover under some conditions. Consequently, a mechanical brake was also installed on the return-side booster drive to increase the tension of the belt entering the tail turnover. A spring-applied, hydraulically released brake was selected to ensure application in case of power failure. Just like the capstan brake, this brake is kept released at all times during operation, and is only applied in case of motor trip or power failure.

Dynamic modeling showed that these two brakes completely eliminated the low tension problem in the tail turnover (Fig. 11). This was later confirmed by field testing.

Conclusions

Preeminent PLC, variable frequency drive or brake manufacturers are often asked to provide the control for their own components. While their design engineers usually have a good understanding of their own equipment, they typically do not understand the control requirements of long overland conveyors. This often results in low reliability, unstable operation or even dangerous operating conditions for the equipment and its operators.

The Essroc conveyor is an example of a conveyor with complex physics. Although relatively light in tonnage, the conveyor is an ambitious system with multiple drive stations spaced far apart, extremely tight horizontal curves and material on both the carry and return sides of the conveyor.

As originally designed, the system was unreliable and expensive to operate. CDI and Essroc worked together to fix the various design and control problems. The final solution involved mechanical and control changes, and required the use of some of the most advanced technology available in conveyor design.

By the end of the project, CDI and Essroc were able to fully correct all the original designers' mistakes. The Essroc conveyor is now operating reliably at full design tonnage.

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