ACTIVE WINCH TAKE-UP SYSTEM

INFLUENCE ON CONVEYOR DYNAMICS

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1. SYNOPSIS

The intention of the paper is to give an indication of the influence of an active winch on a high capacity port loading conveyor's dynamic problems.

Specific focus will be given to the problems experienced with a conventional gravity system and how this was solved by using an active winch system, and the discussion of the starting and stopping trends of the conveyor system.

An existing active winch installation will be used as a case study for this paper. The installation was done on an existing port loading facility in Colombia. The existing gravity take-up was replaced with an active winch system to reach the designed plant capacity which was previously limited because of the dynamic problems on the belt, particularly during power loss conditions. The associated installation risks and design philosophies will be discussed in general.

2. INTRODUCTION

The requirement was to design four active winch systems for a Port loading facility in Colombia. Dynamic problems were noted on four conveyor systems during the ramp-up and commissioning stages of the project once production reached near design capacity for the system. A dynamic simulation was conducted by a third party on these four conveyor systems and it was concluded that using active winches to stop take-up travel during power loss conditions would minimise dynamic effects on the conveyor systems.

Two of the four conveyors were used for stacking and reclaiming material from the train loadout station onto a stockyard. The remaining two conveyors were used to transport the reclaimed coal firstly to a buffering silo and then along a jetty to the ship loaders' boom conveyor.

The design tonnage of all four conveyors was 8000 MTPH with a belt width of 2200 mm and conveyor lengths more than 1000 m. Production of the complete facility was restricted to 6000 MTPH due to the dynamic effects and adverse forces on the conveyor systems.

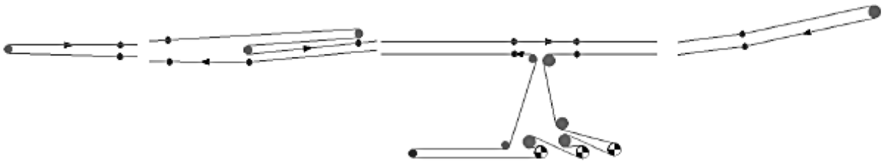

Figure 1: CV-001 & CV-002 Belt Diagram

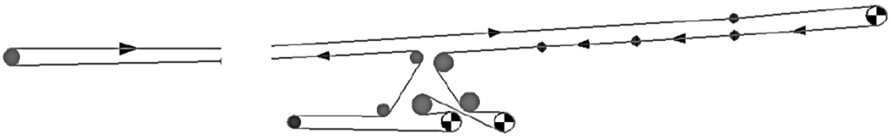

Figure 2: CV-003 Belt Diagram

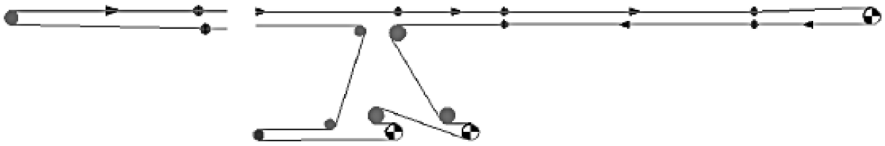

Figure 3: CV-004 Belt Diagram

All four conveyors had VSD drives installed, and used a 120 second velocity curve to speed up the conveyor system to design velocity in a required time. This start-up time was defined during the initial project.

The conveyors use the following stopping procedure:

1) Normal stopping: The conveyor is controlled by the VSD drives to stop in 30 seconds. The VSD drives uses a steady curve to bring the conveyor to a stop.
2) Powered Emergency Stopping: The conveyor is controlled by the VSD drives to stop in 20 seconds. The VSD drives uses a steady curve to bring the conveyor to a stop.
3) Power Loss Emergency Stopping: The conveyor drifts to a stop uncontrolled.

Using the table 1 on the next page, we can see that the Powered Emergency Stopping time was set shorter than the normal drift time of the conveyor. According to the dynamic analysis, this value had to be increased to 30 seconds in order to reduce the dynamic effects on the conveyor system.

Below is a table summarising the conveyor design data (Ormsbee, 2014).

Item	CV-001/CV-002	CV-003	CV-004
Tonnage (MTPH)	8000	8000	8000
Material	Coal	Coal	Coal
Velocity (m/s)	5.2	5.2	5.2
Lift (m)	4	25	9
Length (m)	1425	995	1998
Belt Width (mm)	2200	2200	2200
Belt Class	ST1250	ST1250	ST1250
Starting Time (s)	90	120	60
Stopping Time (s)	25	14.8	25
Original Take-Up Counterweight Tension	79.9	59.8	69.1
Winch T2 Start-Up Set Point (kN)	85	62	75
Winch T2 Running Set Point (kN)	80	62	70
Winch T2 Power Loss (kN)	194	211	201

Table 1: CV Design Data

For the sake of this paper, only CV-004 will be discussed. This was the system that had the biggest dynamic forces and this was the last system to be tested.

3. TAKE-UP THEORY

Conveyor take-ups are required to create adequate take-up tension on the conveyor system to:

1) Transmit mechanical power from drive pulleys to conveyor system in all operating conditions.
2) Limit belt sag between idlers in all operating conditions.

Take-up tension can be created by using the following take-up systems:

1) Manual type take-ups

   Manual type take-ups are normally used in shorter plant conveyors, with horizontal centres smaller than 50 m (Mulani, 2001). This type of take-up will normally have a shorter travel distance which might not allow for surplus requirements. This is the most economical take up system within its allowable parameters. The tension is manually adjusted by ether tension screws, hydraulic cylinders or even winches.

2) Vertical gravity take-ups

   Vertical gravity take-ups are normally found in conveyors with adequate headroom close to the head end to house the take-up counterweight as well as the counterweight travel. The take-up tension is created by a take-up mass, usually steel plates or a concrete mass. This in a cost-effective way to create the required take-up tension, with minimal maintenance required.

3) Horizontal gravity take-ups

   Horizontal gravity take-ups are normally found in conveyors with no headroom to fit a conventional gravity take-up system. The take-up still uses a vertical take-up mass to create the required take-up tension, but the force is then applied to a horizontal carriage through a series of sheave wheels.

4) Active Winch Take-ups

   Active winch take-ups are normally used where none of the previous types of take-ups can be used. A winch take-up uses an electric motor to apply the required torque through a reducer (Gearbox) to create the required take-up tension. A winch system can operate in constrained areas, especially in underground mines. Winch take-ups can be versatile, and system tensions can be changed as required during operation.

To transmit mechanical power to the conveyor system the minimum required take-up tension, must be calculated. This can be calculated by using the following equation:

$$T_2 = T_1/e^{\mu\theta} \qquad 1$$

Were

T$_1$ = Drive Side Tension

T$_2$ = Take-up Tension

μ = Pulley friction factor

θ = Pulley wrap angle in radians

The take-up tension must also ensure that required sag is maintained. The belt sag must be checked on critical low tension areas along the conveyor system to ensure the belt sag is limited to a maximum of 2%.

The minimum T2 tension is selected based on the highest minimum T2 tension required. Once the minimum required T2 or take-up tension is calculated, the take-up movement is the next critical aspect in take-up design.

Take-up movement is caused due to belt stretch in the conveyor system and consist of the following:

1) Permanent Elongation
2) Elastic elongation

The permanent elongation is the belt stretch that occurs over long periods of time, whereby the belt will stretch and not return to the previous length. The CMA guideline gives these values as a percentage value of the belt length used on a conveyor system. Please see table below (Shortt, 2014):

Belt Type	Permanent Elongation
Plied Fabric	1.5% of belt tape length
Solid Woven Fabric	1.5% of belt tape length
Steelcord	0.05% of belt tape length

Table 2. CMA Permanent Elongation Values

The elastic elongation of a conveyor system is the amount of belt stretch due to changes in belt tensions in different conveyor belt load cases. Once the load cases change or tension is completely removed from the system, the belt will return to the original belt length. The first principle calculation to calculate the elastic stretch of a belt will be discussed below.

During stationary periods, the belt tension distribution for a simple horizontal belt will be equal along the length of the belt as the take-up or T2 tension, shown in the figure below:

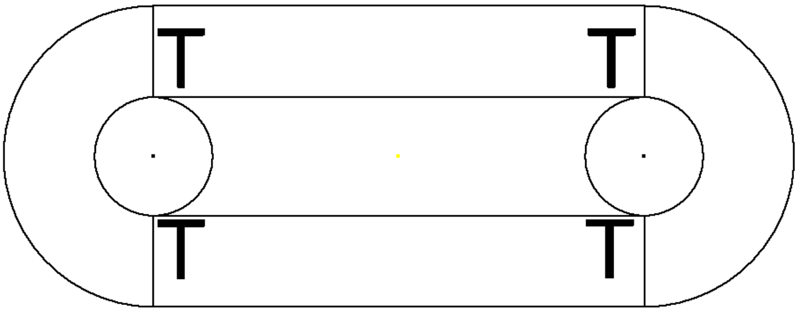

Figure 4: Simple Stationary Belt Tension Diagram

Once the conveyor starts up, and an effective tension (Te) is applied to the conveyor system through the drive pulleys, the belt will stretch due to of the increase in the average tension in the system.

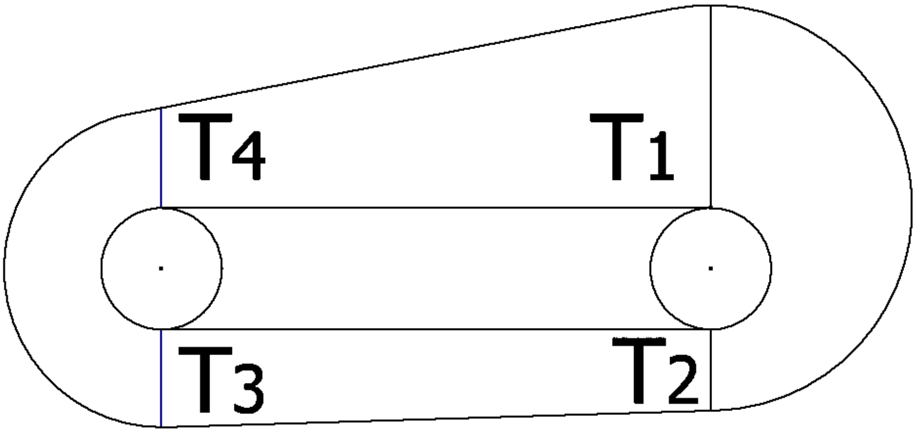

Figure 5: Simple Running Belt Tension Diagram

This increase in average tension in the conveyor system, will cause the conveyor belt to stretch as predicted by the following formula (Mulani, 2001):

$$\delta y = \frac{T' - T}{B} \cdot \frac{y}{E} \qquad 2$$

Where:

T’ = New Average Belt Tension

T = Original Average Belt Tension

B = Belt Width

Y = Original Belt Length

E = Modulus of elasticity

In order to calculate T’, the average tension in each strand can be calculated and along with the belt strand length, be added up proportionally along the conveyor length.

It is therefore important to design a take-up system that must be able to apply the minimum amount of take-up tension and that must be able to accommodate the maximum required belt stretch.

More complicated take-up systems can be designed if there are additional system constraints, like headroom or take-up length constraints. Multiple lap take-up systems and/or sheave arrangements can be incorporated, but this will not be discussed in this paper.

4. EQUIPMENT DESCRIPTION

The active winch in this project consisted out of the following items:

1) Electric motor (45 kW)
2) Reducer (Gearbox)
3) Brake Mechanism (Fail to safe)
4) Drum complete with rope
5) Load Cell
6) Electric Panel complete with VVVF

The electric motor is controlled by a Variable Voltage Variable Frequency drive (VVVF) inside the electric panel. Once the start-up command is received from the conveyor, the VVVF will hold the electric motor at zero RPM. The brake mechanism will be given the command to release and the VSD will ramp up the motor torque to keep zero RPM. The load cell will send an electric signal to the electric panel and the VSD will control the motor speed and direction of rotation to adjust the tension to a pre-set value. A pre-set dead band is used to allow the winch to keep the tension in this range.

Whenever the conveyor has reached full speed, a second running take-up tension can be pre-set to allow a reduction in running tension. Once the take-up tension is within the dead band for a pre-set period, the winch will go into sleep mode, where the brake mechanism will engage and allow the electric motor to be shut down to save energy. Whenever the take-up tension moves out of the dead band, the winch will wake up and adjust the tension accordingly.

During a power loss or emergency stop condition, the winch can be set up to hold the carriage steady during these extreme conditions and therefore reduce dynamic belt movement along the conveyor. Once the conveyor has come to a standstill, the winch will adjust the take-up tension to the start-up tension and shut down until the start-up signal is received from the conveyor.

During a normal stop situation, the winch can be set-up to either keep a pre-set tension in the take-up system, or it can hold zero movement until the stopping sequence is complete. Once either one of the above-mentioned sequences is complete, the winch will adjust the tension and shut down until starting signal is received from the conveyor.

The winch is also fitted with a manual local control panel that can be used to release the tension in the take-up system if maintenance is required. It can also be used to manually release stored energy in the event of an over tension trip condition or if the take-up carriage has been wedged on the rails.

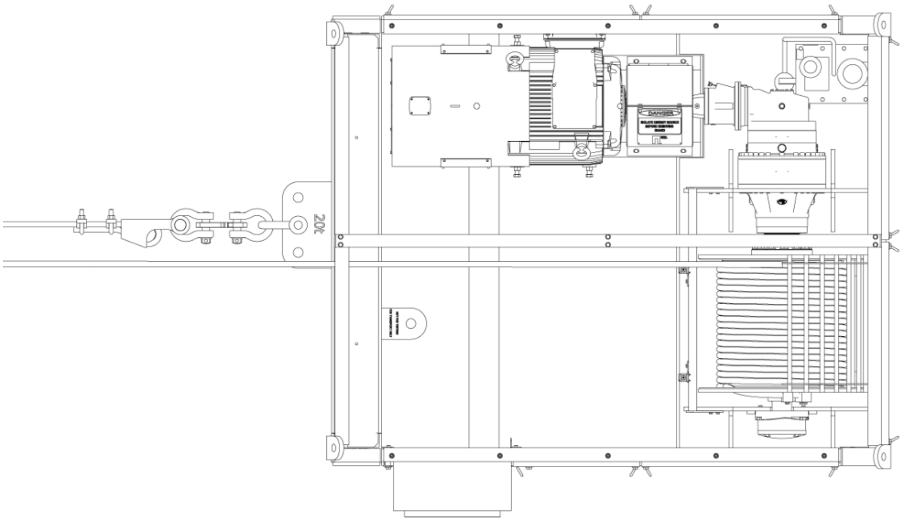

Figure 6: Active Winch Top View

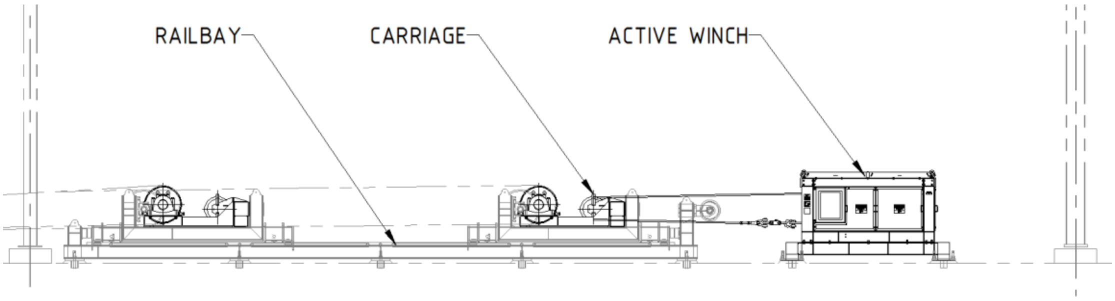

Figure 7: Take-Up System Layout

During the design phase of the project, the client had the following requirements, and this was then used to design and optimise the winch:

1) To Pre-tension the conveyors at start-up
2) To reduce the running T2 tension and keep a constant tension during all running conditions
3) To handle aborted start system tensions
4) To keep a constant tension during controlled stop conditions
5) To keep the carriage stationary during power loss and e-stop conditions

These requirements were determined by an external conveyor consultant.

5. PROJECT CHALLENGES

During the project, some major challenges had to be overcome to complete the project successfully.

5.1: Original Conveyor System Problems:

The port loading facility encountered some major problems during the ramp up of the facility during the commissioning stage of the initial construction. These problems could not be rectified during this stage and could only be rectified during port operation. The end user reported the following problems:

- Excessive counterweight movement during power loss and E-Stop conditions. This also included a power loss test where the counterweight moved up to the mechanical stops of the take-up structure, breaking the steel wire rope before crashing down onto the jetty.
- Excessive belt sag and slap during the above-mentioned conditions. As the dynamic waves moved through the conveyor system, the belt would sag excessively between the idlers and then slap up, knocking and breaking some idlers and even idler cradles from the structure. This was at its worst close to the tail area where the two dynamic waves would meet.
- Numerous pulley bearing failures on different conveyors because of high dynamic forces in the system.
- Numerous idler and idler frame failures during uncontrolled stoppages.

5.2: Design Challenges

During the design stage of the active winches, the installation and positioning of the winches was a critical design aspect. The winches needed to be installed in such a manner to reduce standing time to a minimum for the port loading facility to function as normally as possible. The client restricted the total conveyor shutdown time to two days per conveyor.

The winches also needed to be placed within the areas of the take-up system to keep modifications to existing structures to a minimum. A dynamic simulation was completed on the four most critical conveyors. This showed that the take-up tension would rise from 80 kN running tension to 212 kN during a power loss conditions.

The winches had to be designed for this worst-case tension, and all low-tension areas along the conveyor systems had to be checked to ensure the structures would still be adequate for this rise in tension. The winding speed also had to allow for a maximum take-up trolley speed of 0.3m/s during fully loaded starting conditions. This added some challenges in the programming of the PLC system to adjust winding speed of the winch during operation to allow for seamless operation during any starting or operating conditions.

5.3: Installation Challenges:

Once installation started, it was also noted that that there were some discrepancies between the “as built” drawings and what was installed on site. On one of the conveyors, the counterweight hold down bolts were shown as M36 bolts whereas on the “as built “drawings only M24 bolts were installed. This forced the project team to add additional bracing between the winch base and the existing take-up structure in front of the winch and conveyor trestles behind the winch. This reduced the turnover force on the base sufficiently for the M24 bolts to be adequate.

Some of the low-tension pulleys had to be changed to handle the increase in tension during aborted start conditions. Most of these pulleys were the take-up pulleys, low tension bend pulleys and in some cases the tail pulleys. In all cases the bearing sizes increased because of an increase in shaft diameter. New pulley stools had to be fabricated for the new plummer blocks. There were no stools installed on the tail pulleys, so the pulley centre height increased by 10-15 mm from the existing structure. The return- and carry strand idlers were therefore shimmed to ensure that the beltline was supported as needed and to ensure the small change in belt line would not affect the first few sets of idlers negatively.

5.4: Site Optimization:

During the commissioning of conveyor take-up systems for CV-001 and 002, some valuable site information was gathered which helped with the optimization of the CV-004 conveyor take-up system.

Winch Speed:	The minimum winch speed gain was modified to ensure the set point was reached in the required time, and to minimise overshooting of the set point and for the winch to re-adjust again. This was especially observed where the winch adjusted during normal running conditions and was continually adjusting due to over or undershooting of the set points.
Winch Reaction Time:	The winch reaction time was also adjusted from 2 to 5 seconds to ensure that enough time is given to allow the system to recover once an abnormal reading or situation is picked up. This will keep the winch stable through some oscillating readings.
Winch Power Loss Function:	This was changed after some very high T2 tension readings were observed during testing. The winch program was changed to instead of applying the brake immediately, keep zero speed on the carriage and once a certain tension is reached, allow the motor to slip and release some of the tension into the system. This value restricted the T2 peak tension and ensured that take-up movement was still restricted as previously required.

5.5: Post Commissioning Problems:

After the winches were commissioned, the client had a few questions and some teething problems that we had to help with.

Shortening E-Stop Time: The client wanted to reduce the time for the conveyor system to stop during an E-stop from the current 25 seconds to 15 seconds. Doing so, the client reported much higher forces during this sequence. (Loadcell is limited to 230 kN, and this value was exceeded). The client was requested to revert to the previous stopping time, as this was outside the winch design specification.

Problematic Pressure Switch: The active winch system used a hydraulic power pack to release the fail to safe hydraulic brake. The power pack is equipped with a pressure switch to indicate when the brake release pressure is released. This switch intermitted malfunctioned and even after it was replaced, still had the same problems. This unit was fitted to a winch, 220m from the MCC. The on-site electrician inspected the problem and found that due to the length of cable on the installation, the control voltage dropped well below the 24V used on the system. To solve the problem, a new cable was installed in parallel with the current installation, which reduced the resistance in the cable.

6. ACTIVE WINCH PERFORMANCE

The graphs in this section were gathered during site commissioning and optimization. These graphs were taken from CV-004 with a full production rate of 8000 MTPH. During testing, the conveyor loads were gradually increased from Empty load until 8000 MTPH. During each of the tests, the loading would be set with the plant Production software and measured with a calibrated belt scale used to determine material load on the conveyor.

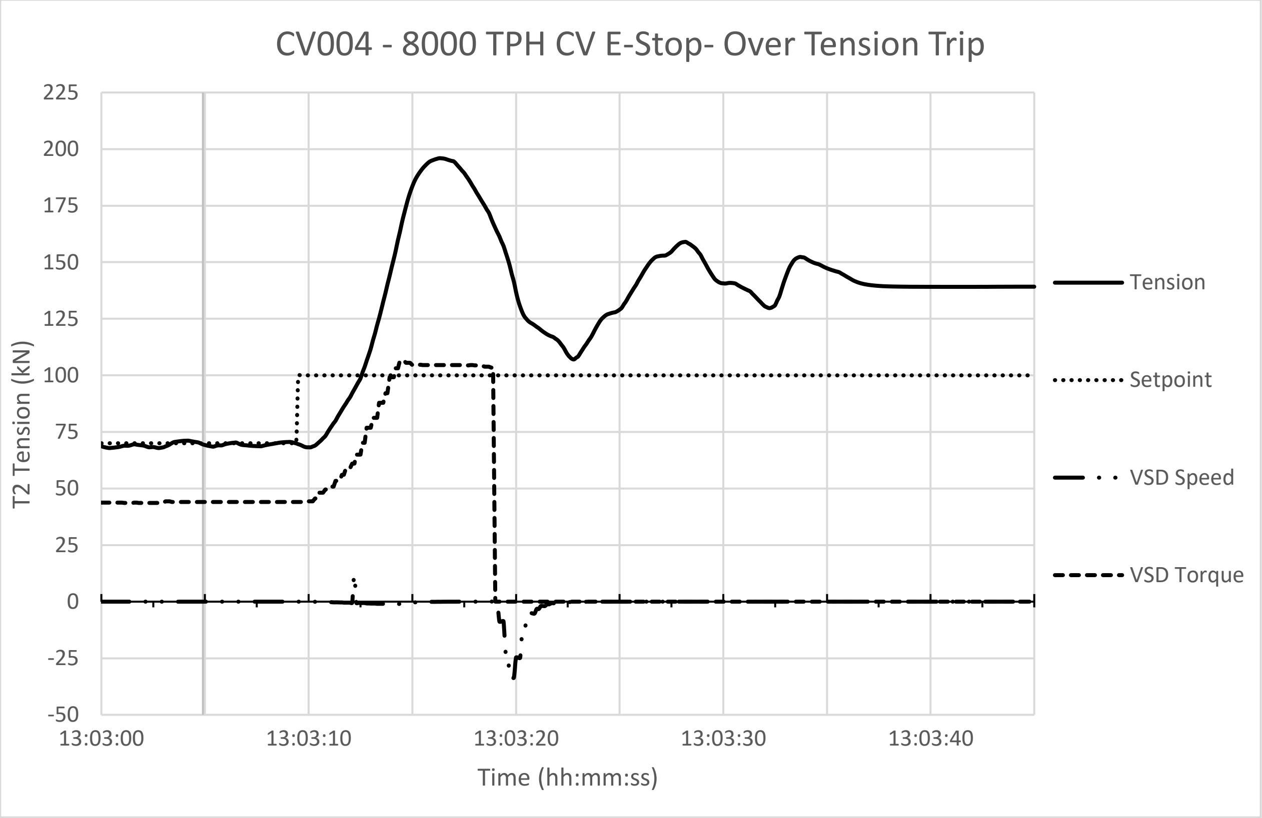

Figure 8: CV004 E-Stop

Figure 8 shows the take-up tension during an E-stop situation on the CV004 conveyor system. Once the E-stop is activated, the tension set point is increased and the tension immediately starts to rise and peaks at over 175 kN for more than 5 seconds. This however activates the trip on the winch system and the brake is activated. This causes the VSD torque to drop down to zero, and no movement is possible in the carriage. The dynamics moved through the system and after about 25-30 seconds the conveyor is stationary and the take-up tension has increased from under 75 kN to over 125 kN. Once the conveyor system was inspected for any possible damages, the over tension trip was reset before the conveyor system could be restarted.

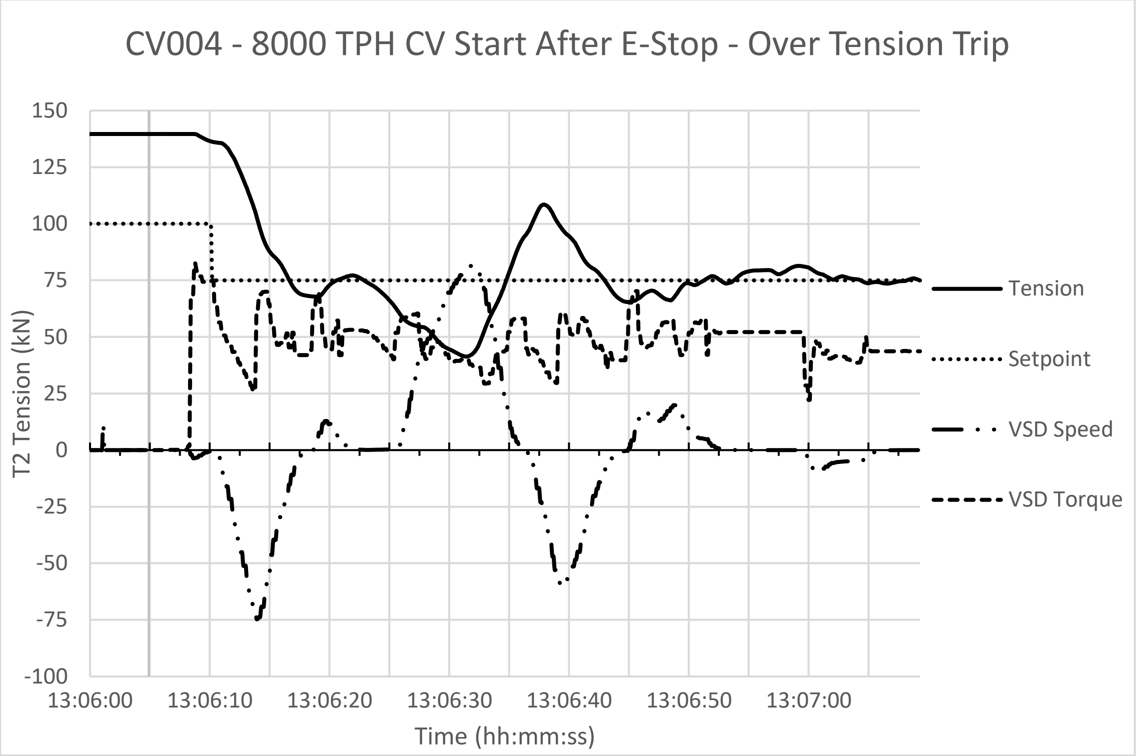

Figure 9: CV004 Start after E-Stop

Figure 9 shows the start-up tension inside the take-up system with the active winch system. Once the start signal is given, the tension is released from the 140 kN mark to the set point tension. As the set point tension is reached, the drives start up and creates slack in the take-up area. The tension drops below the set point value and the winch reacts to increase the tension to prevent drive slip. The winch overshoots on the set point tension and once it releases some of the take-up tension, the system is in motion and the conveyor speed is ramped up. The winch settles down and no major peaks are created. The total carriage movement during this time was about 150-300 mm.

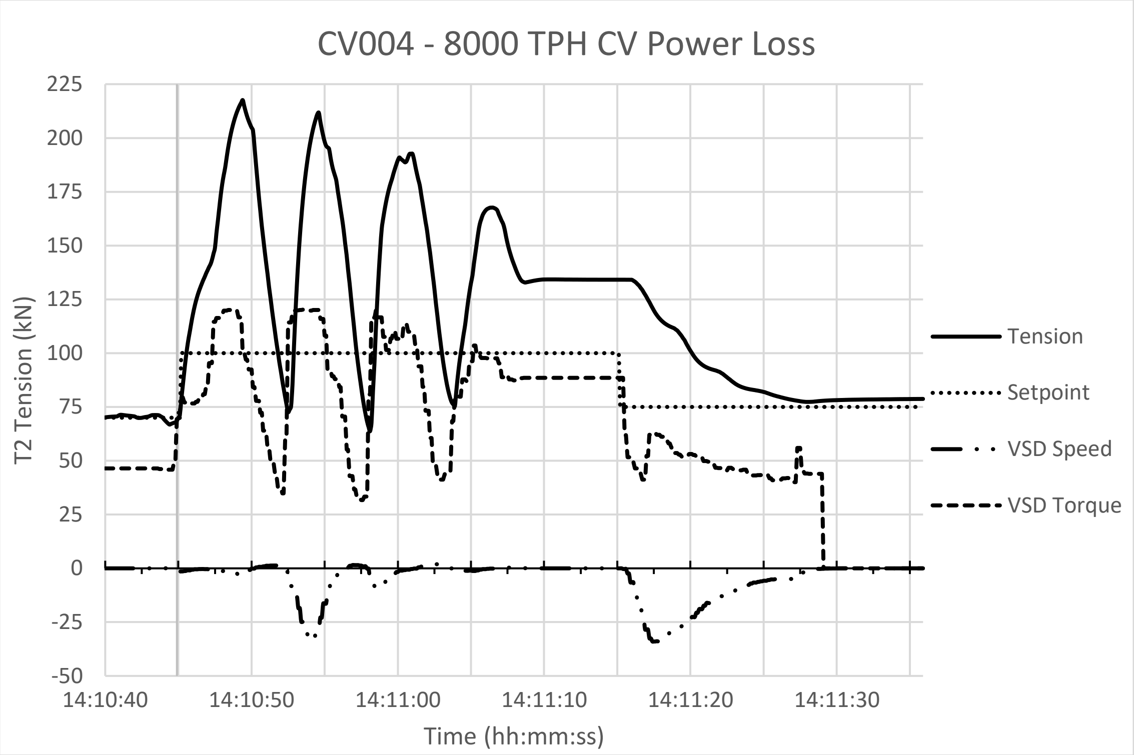

Figure 10: CV004 Power Loss 8000 TPH

Figure 10 shows the take-up tension during a power loss condition at full operating capacity. Once power is lost on the drive system, an immediate tension spike is created spiking up to 215 kN. After this spike, there are three less intensive spikes present in the system before the conveyor system comes to a standstill, after which the winch reacts to release the tension build-up from 130 kN to the required set point value. The winch does not trip on overload during this period even after higher tension values are registered, mainly due to the short time of the dynamic spikes. The winch remains active and the VSD lets the motor slip on three instances, as shown by the negative VSD speed graph. The carriage movement was neglectable negligible? and can be excluded.

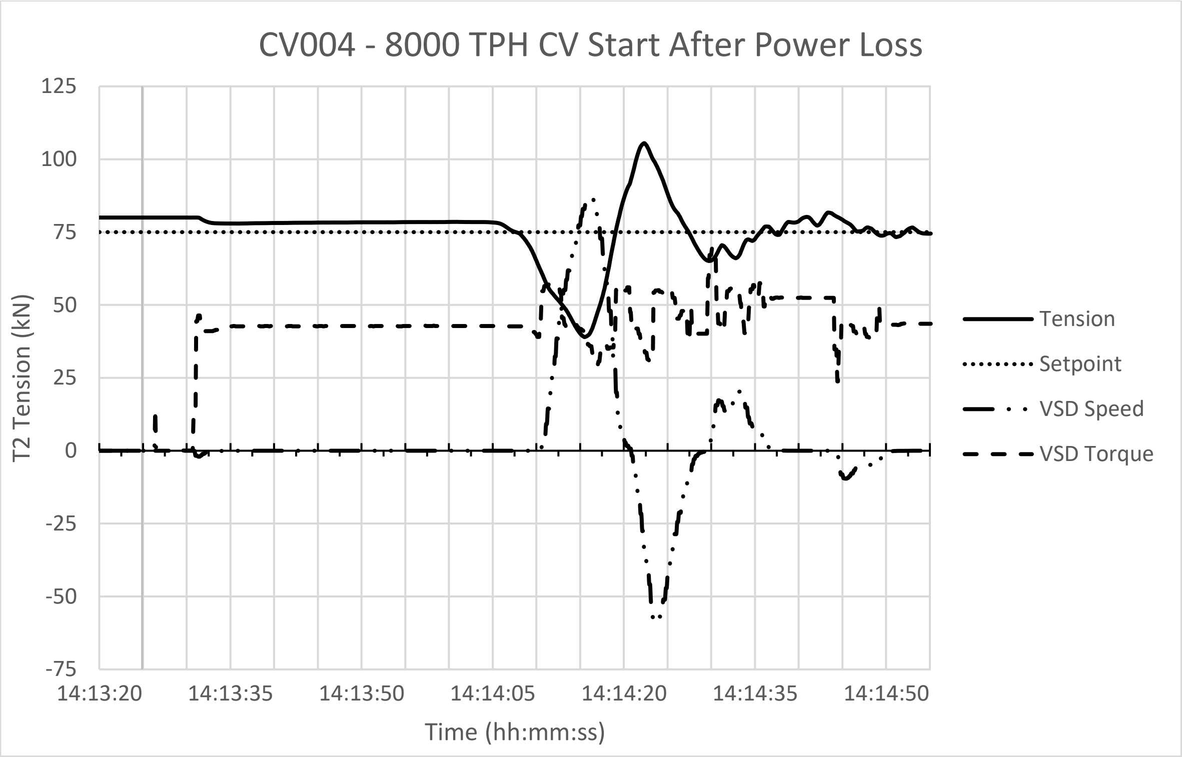

Figure 11: CV004 Start After Power Loss

Once the start command was given, the winch adjusted the take-up tension and then waited for the drives to start. Again it can be seen that once the drives started, the take-up tension drops down before the winch reacts and increases the take-up tension and then overshoots the set point. Once the winch overshoots the set point, it reduces the tension where after the system is more stable and no further peaks are observed. The approximate carriage movement during this time was 300 – 500 mm.

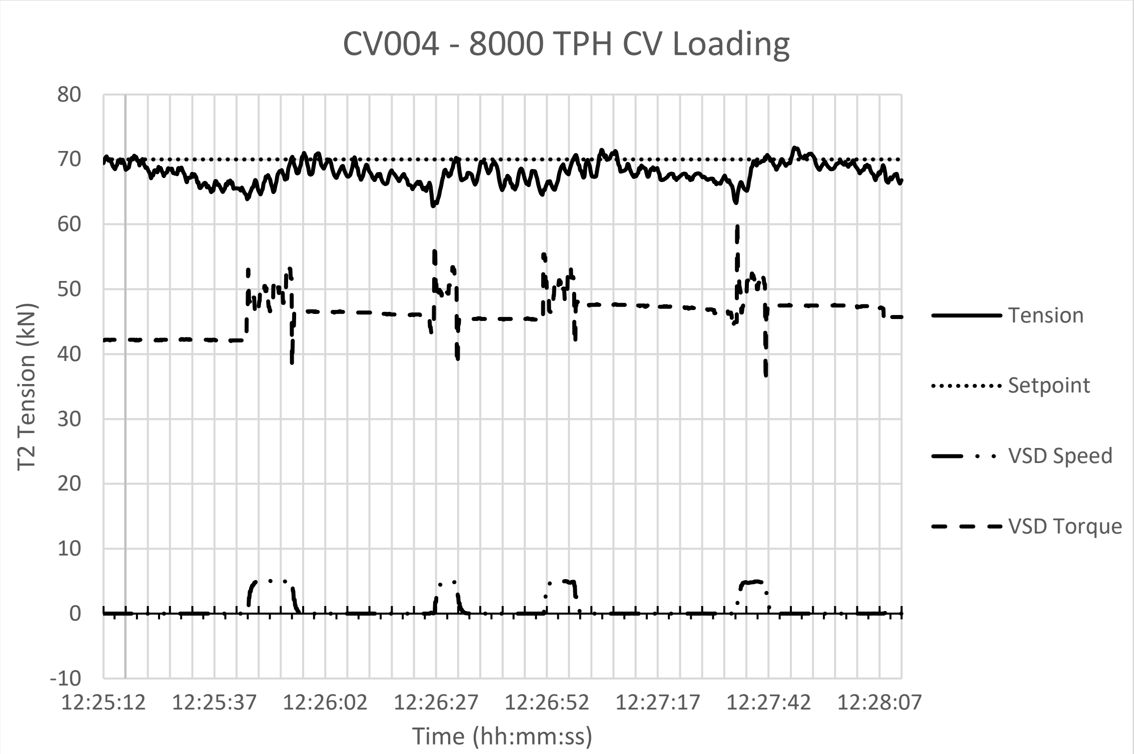

Figure 12: Conveyor Belt Loading

Figure 12 shows the take-up tension and reaction during the loading of the conveyor system. This graph was captured during the testing and optimization of the active winch system. The conveyor belt was operating empty and was then loaded at 8000 MTPH in order to complete the required tests. As the material was loaded onto the conveyor system at a rapid rate, the belt would stretch and this would cause the tension to drop at a slow rate. Once the tension moves out of the “operating band”area, the winch reacts by increasing the tension which in turn takes up the additional stretch caused by the higher belt tension. This occurance can be seen four times.

7. CONCLUSION

Based on the information provided in this paper, it can be said that an active winch system can be used in solving dynamic problems on existing equipment and conveyor systems.

When using the correct design philosophy and principles, existing and new high capacity systems’ dynamic problems can be resolved by using active winch systems to change the take-up tensions in the system as required to ensure safe operation of a conveyor system.

If dynamic problems are encountered on existing equipment, the possibility is available to install an active winch system, and to design a fit for purpose system given small constrained spaces for new equipment.

If dynamic problems are flagged during the design stage of a conveyor system, it is possible to design the system with a cost effective active winch system that can improve the expected dynamic problems , and can be designed to easily be modified if it is found that site conditions are different to the design assumptions.

As with all designs, there are areas of improvement that can be investigated. First, additions to the software that can allow different reaction speeds, in both the winding in and winding out function during different conveyor load cases. This can allow the winch system to react in different ways, depending on what the conveyor system is doing. This however can only be done if sufficient communication can be created between the winch PLC and conveyor program.

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