INNOVATION IN DESIGN OF ELECTRONIC TENSION CONTROLLED TAKE-UP WINCH

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1. INTRODUCTION

The modern high speed, large capacity, long length conveyors have created a need for an alternative, innovative and cost effective method to tension these high production machines. As conveyor belts get longer and wider, the need for larger and faster take-up systems increases. This is due to the tension drop that occurs at the take-up section during start-up. The winch is required to take up this slack as quickly as possible to prevent slip on the drive pulley. If the winch is too slow, the belt slip can create trip conditions or even ignite from heat generation due to friction. Over tensioning is also not good practise and decreases the life of all conveyor components as well as the life of the belt itself.

With the goal of maintaining accurate positive tension during start-up and avoiding tension changes due to uncontrolled starting and stopping, the solution is a combination of various systems that offer an adaptable take-up system.

The system simulated in this presentation is a theoretical example of an existing belt currently in operation.

2. THE SYSTEM

The take-up system of a conveyor belt generally comprises a gravity system, fixed take-up system or an automatic winch system.

The focus of this presentation is on an automatic winch system combined with a hydraulic cylinder and mechanical overload-protected slip clutch on the winch.

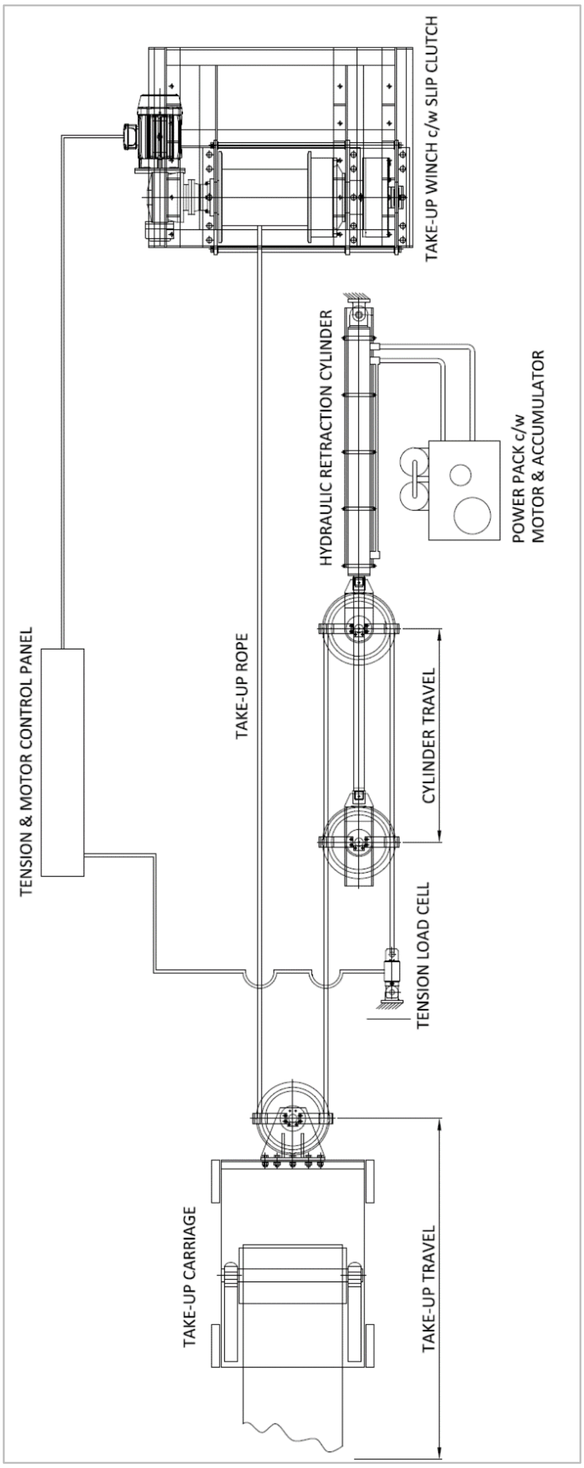

Figure 1. Typical conveyor take-up winch system with VFD, clutch and cylinder

Functional Description of Main Components as per Figure 1

- Take-up winch and sheaves:

  An electro mechanical device to tension conveyor belt and hold tension. The winch is connected to the conveyor take-up carriage by steel wire rope around a sheave wheel.

- Tension control panel with variable frequency drive (VFD) and load cell:

  The winch motor torque is controlled via the variable frequency drive, electrical panel and load cell to keep constant tension on the take-up carriage.

- Mechanical overload protected slip clutch:

  Mitigates and limits the tension in the take-up system mechanically by allowing the mechanical drive to slip and is not dependent on electrical power.

- Hydraulic low tension protection cylinder and power pack with accumulators:

  Fast retraction of the extended cylinder removes rope from the system thereby restoring the correct tension in the belt. Accumulators ensure functionality in power failure conditions.

The take-up winch, complete with mechanical overload-protected slip clutch used in conjunction with the electronic tension controller, variable frequency drive and the hydraulic low tension protection can react to, and accommodate, all starting and stopping conditions encountered in the modern high speed conveyor.

This includes momentary shock loads caused by unplanned stops and power failures.

The winch and the electronic tension controller with variable frequency drive takes care of the normal running and pre-start tensions. The mechanical overload slip clutch controls any tension overloads or spikes. This is done by allowing the mechanical clutch to slip immediately and reduce the overload tension by paying out rope into the system, thereby reducing the tension.

When the opposite occurs and low tensions are created, this is immediately rectified by the fast retraction of the extended hydraulic cylinder removing rope from the system, thereby restoring the correct tension in the belt. This is the only system other than gravity which can make adjustments to the fluctuating belt tension without continuous electrical power being supplied.

This system would be especially beneficial for incline conveyors and longer conveyors generally experiencing tension loss or high tensions during uncontrolled stops.

Advantages and specific uses of the added main components to the winch system:

A. Tension control panel with variable frequency drive and load cell.
B. Mechanical overload-protected slip clutch.
C. Hydraulic low tension protection cylinder and power pack with accumulators.

A. Tension Control Panel with Variable Frequency Drive and Load Cell.

The addition of the variable frequency drive control system has the following advantages over older style direct on-line (DOL) starting:

- Controlled starting via the variable frequency drive:

  This minimises shocks generally caused by direct-on-line (DOL) starting on winch gearing/components, conveyor take-up trolleys, pulleys, idlers and any other components in the conveyor systems.

- Reduced power consumption on winch as torque is limited in the drive
- Virtually no brake wear as the motor will be held under full torque at 0 Hz when the brake is applied for parking
- Faster response due to the winch staying active during the start-up/pre-tension phase
- Pure torque control in the variable frequency drive via proportional-integral-derivative (PID) loop ensures tension is applied and maintained at the running tension. No more over or under shooting of tension level
- Winch control speed can be easily adjusted in the drive for finite control for higher or lower speeds within the limits of the system.

B. Mechanical Overload-Protected Adjustable Slip Clutch.

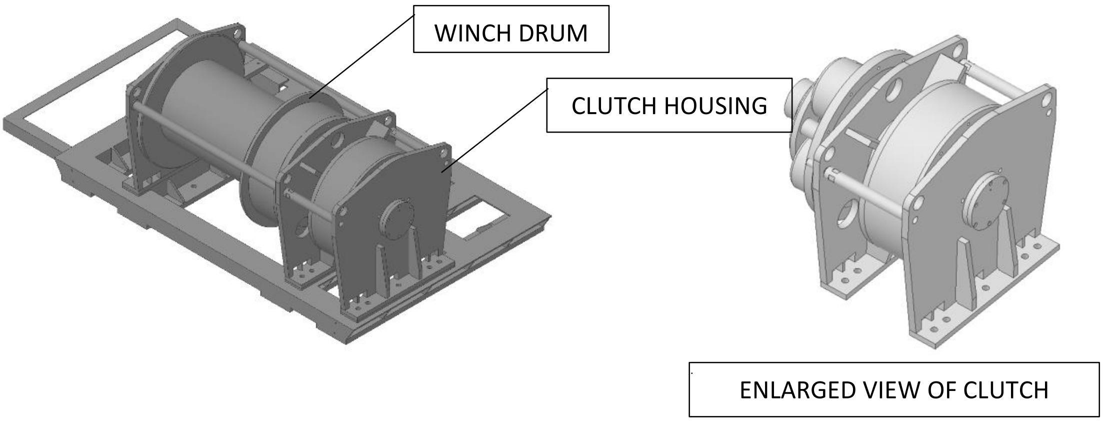

Figure 2. Typical take-up winch fitted with low speed adjustable slip clutch

- The slip clutch is fitted directly onto the final epicyclical gear on the winch. The slip clutch consists of a multi-plate friction clutch and is adjustable within a range sized to the applicable winch rating. The friction plates and steel discs are pressurised by compression springs.

When over tension occurs, the rope pulls on the drum and it starts to turn. The ring gear is connected on to the drum flange. As the planet gears are engaged into the ring gear, the only item that can turn is either the pinion or the carrier of the planet gears.

The clutch is connected directly onto the carrier and when the clutch is at slip point the carrier starts to turn until the friction and pressure between the slip surfaces are in the range to stop slipping.

Minimal revolutions take place when slip occurs, preserving clutch life and ensuring that the primary gearbox, secondary gearbox, brake and motor are protected. Benefits include:

- Controlled mechanical overload payout during starting and stopping of automatically controlled conveyors
- It offers instantaneous reactions to tension spikes, thus protecting and extending the life of the belt, belt pulleys, idlers, tensioning rope, sheaves and the winch
- Dissipation of tension spike energy by allowing the winch to payout, at a preset tension level, even when the brakes are locked. This feature is one of the big advantages of a gravity take-up system within an automatic tension controlled system
- This mechanical payout system is the only method, besides gravity, that can provide overload protection/response during a power off/failure or emergency stop condition.

C. Hydraulic Low Tension Protection Cylinder and Power Pack with Accumulators.

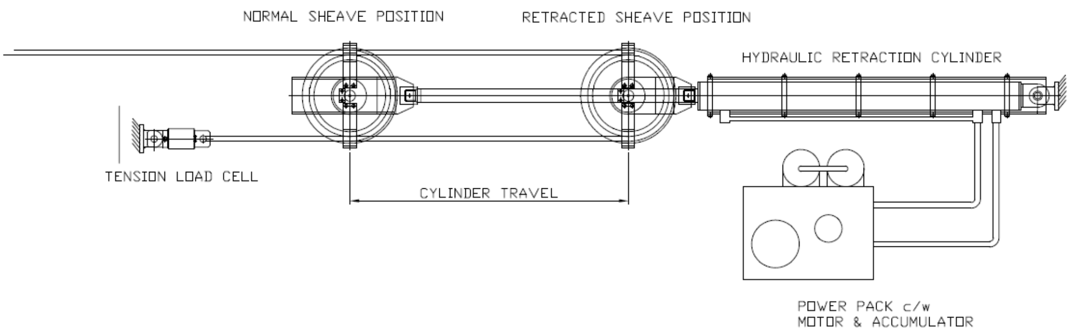

Figure 3. Typical hydraulic low tension protection cylinder system

- The cylinder is set to a pressure/tension just below the running tension of the conveyor. This is backed up by the winch taking in rope simultaneously with the cylinder
- When low tensions are created, this is immediately rectified by the fast retraction of the extended cylinder removing rope from the system thereby restoring the correct tension in the belt
- The winch extends the cylinder to the fully extended position due to the tension level set above that of the cylinder. The cylinder is now again ready for any low tension

- The power pack is fitted with an accumulator which stores sufficient hydraulic pressure to counter low pressure spikes even in the event of a total power failure.

3. CASE STUDY – THEORETICAL ONLY - OVERLAND CONVEYOR

Conveyor length [m]	3 972.0
Conveyor lift [m]	-2.14
Design output [t/h]	900
Design speed [m/s]	2.3
Belt width [mm]	1 200
Belt type	Steel cord
Belt class [N/mm]	1 000
Top idler spacing [m]	1.2
Return idler spacing [m]	2.6
Idler roll dia. [mm]	127 (top and return)
Trough angle [deg.]	45
Take-up type	Electric winch
Take-up location	Head end
Drive location	Head end
No. of drives x number of dr. pulleys	2 x 2
Total installed power [kW]	2 x 250
Product conveyed	Bauxite (Aluminium ore)

Table 1. Conveyor parameters

CONVEYOR DYNAMIC SIMULATION PARAMETERS

3.1 Starting Concept

Start-up simulation has been performed utilising a staged velocity ramp. The conveyor drives are ramped over 150 seconds in stages to ensure smooth ramp over the entire start-up period. Total time to reach full speed is 150 seconds.

3.2 Stopping Concept

In all instances stopping of the conveyor was achieved by de-energising of the motor.

3.3 Load Conditions

All simulations were performed for a fully loaded condition.
Operational cases considered are:

- normal stop
- start-up
- aborted start-up

3.4 Winch Operation Conditions

- Fixed winch operation:
  Fixed winch is stationary during all conditions and only pre-set initially.
- Winch active DOL – constant speed winch operation:
  The winch is driven via a direct-on-line panel and cannot vary the take-up speed.
- High and low tension protection active while the winch is locked:
  Winch is fixed but slip clutch and hydraulic cylinder is active.
- Both winch and protection systems active:
  The winch is driven via a direct-on-line panel and cannot vary. The take-up speed, slip clutch and hydraulic cylinder are active.

For the above conditions the following parameters were used:

High tension protection was set at 137 kN (total pull at the take-up trolley) while low tension at 41.4 kN (total pull at the take-up trolley).

Both values were based on the results of the original conveyor dynamic simulations.

In addition, a limited set of simulations were performed for the reduced maximum high tension of 68.5 kN (50% of the original figure) and increased minimum tension of 47.4 kN.

VFD winch operation

For the above condition the following parameters were used:

The winch operates as a fully live system, that is, energised and ready to react to the tension changes. The variable frequency drive maintains constant torque and therefor constant belt tension at the take-up location. Subsequently, trolley speed limit was introduced as an additional measure of control. The speed limit was set at 2 x nominal trolley speed of 0.07 m/s. Once the limiting speed was reached, the variable frequency drive was required to change motor torque and restrict trolley movement.

For the purpose of the simulations, a nominal trolley speed of 0.07 m/s at rated winch operation was assumed. This figure is based on the maximum speed that can be achieved with a standard take-up winch running at 60 Hz via a variable frequency drive. Winch speed at 50 Hz is 7 m/min and at 60 Hz is 8.4 m/min.

It was assumed that proper torque control is achieved over the full range of motor rpm and frequencies.

All simulations were based on the nominal 21.7 kN belt tension at the take-up.

4.0 RESULTS OF THE SIMULATION FOR THE FOLLOWING CONDITIONS:

- Fixed winch operation
- Winch active DOL – constant speed winch operation
- Winch inactive, high and/or low tension protection active
- Both winch and protection systems active.

4.1 Conveyor Stop

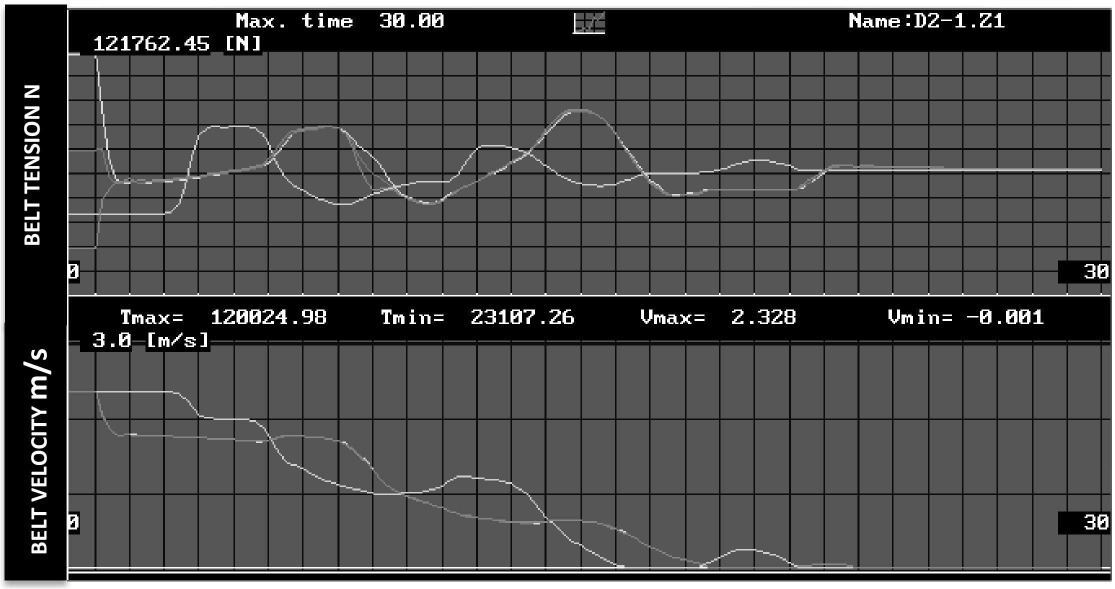

Figure 4. Fixed winch operation. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

Conveyor stop with the inactive winch is characterised by the following:

- Significant belt tension and velocity oscillations (tension reaches up to 80% of the maximum normal run value) are present over the full length of the conveyor
  - Once the motors are de-energized, belt tension on both sides of the drive pulleys is equalized i.e. head tension (blue line) is reduced while the take-up tension (pink line) rises
  - Belt tension and velocity at the tail end (green line) follows the pattern of the head end, however, due to the length of the conveyor, is offset in time
  - Once the conveyor stopped, belt tension at all four locations come to one common value.

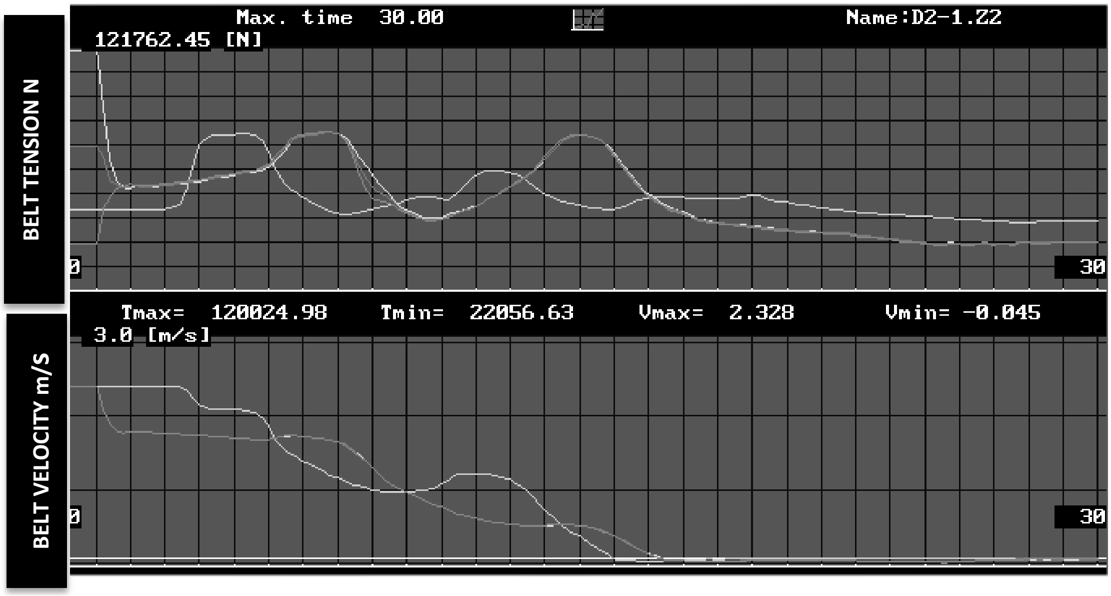

Figure 5. Winch active DOL– constant speed winch operation; trolley moving at 0.06 m/s. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green),head (blue), after drive pulley T2 (red), take-up (pink)

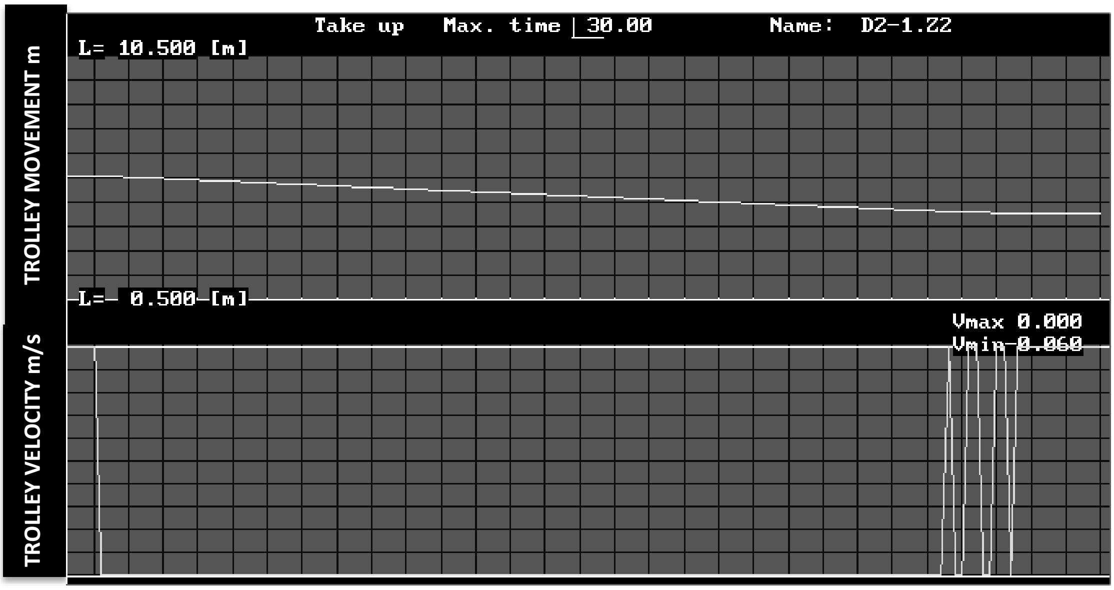

Figure 6. Winch active DOL– constant speed winch operation; trolley moving at 0.06 .Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

Figures 5 and 6 show the simulation result when the take-up winch remains active once the drives are de-energised. Due to the winch being active and paying out rope, the take-up trolley continuously moves, lowering the tension.

The results can be summarised as follows:

- While the winch attempts to maintain pre-set tension on the belt, its speed is too low and as a consequence oscillation of belt tension can be noted in a similar pattern to the fixed winch case (compare Figures 4 and 5)
- On the positive side, trolley movement reduces peak loads to about 65% of the maximum normal run tension
- The winch remains active after the conveyor has stopped, bringing head end belt tension to the pre-set level.

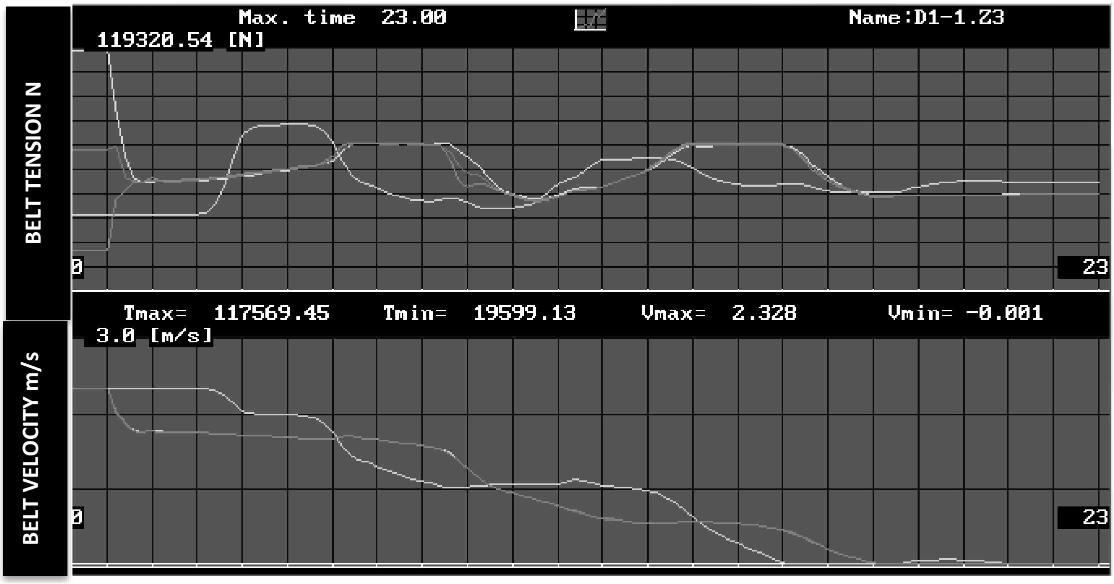

Figure 7. Winch inactive, overload protection (slip clutch) installed. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

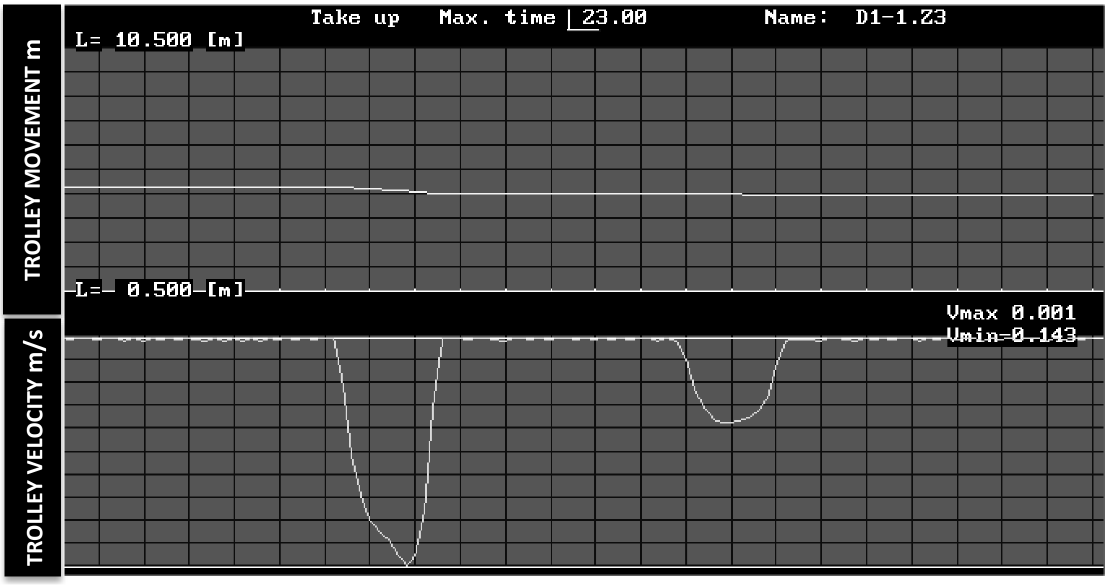

Figure 8. Winch inactive, overload protection (slip clutch) installed. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

As presented by Figures 7 and 8, introduction of an overload protection system (slip clutch) influenced performance of the conveyor during stopping. As stated in Paragraph 3.4, the overload limit was set at 137 kN of total pull at the take-up trolley (2 x 68.5 kN belt tension).

The following can be observed:

- For approximately 5.5 seconds after the drives have been de-energized, the pattern of belt tension and velocity change is identical to the fixed take-up system
- The overload protection system comes into action when the tension limit is reached after 5.5 seconds and its action is manifested by a flat top belt tension pattern at both the head end and the take-up (Figure 7, blue and pink lines, also compare with Figure 4)
- Overload protection system's action is reflected in the trolley movement as shown by Figure 8 (blue line, first trolley velocity spike at maximum of 0.143 m/s)
- The second time the system reacts, approximately 13 seconds after de-energizing of drives however, the reaction is of significantly decreased magnitude (see Figures 7 and 8).

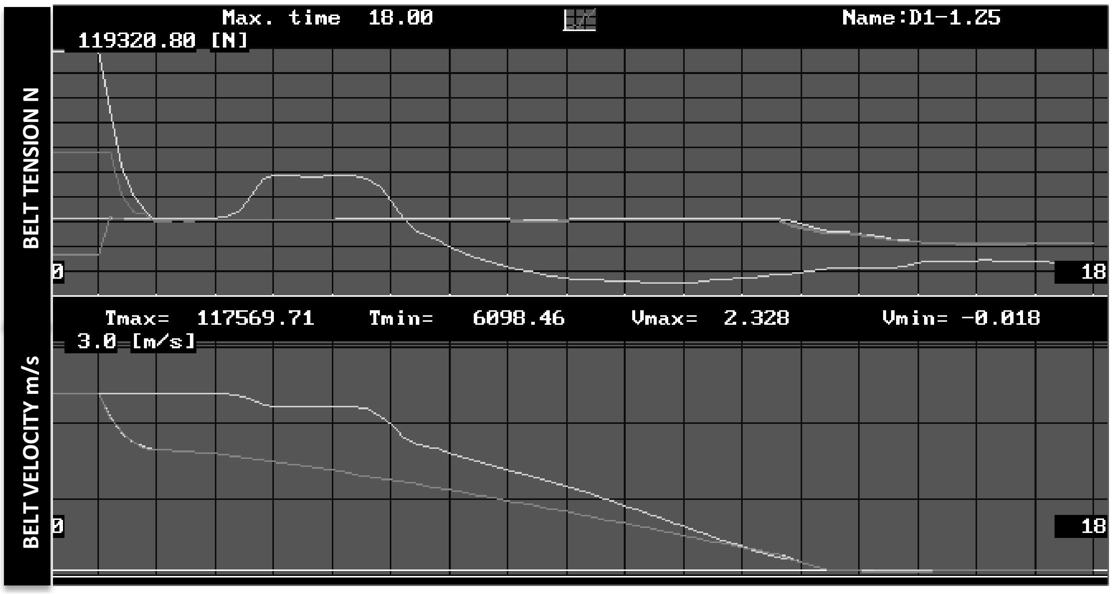

Figure 9. Winch inactive, overload protection (slip clutch) installed – set at 68.5 kN. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), take-up (red)

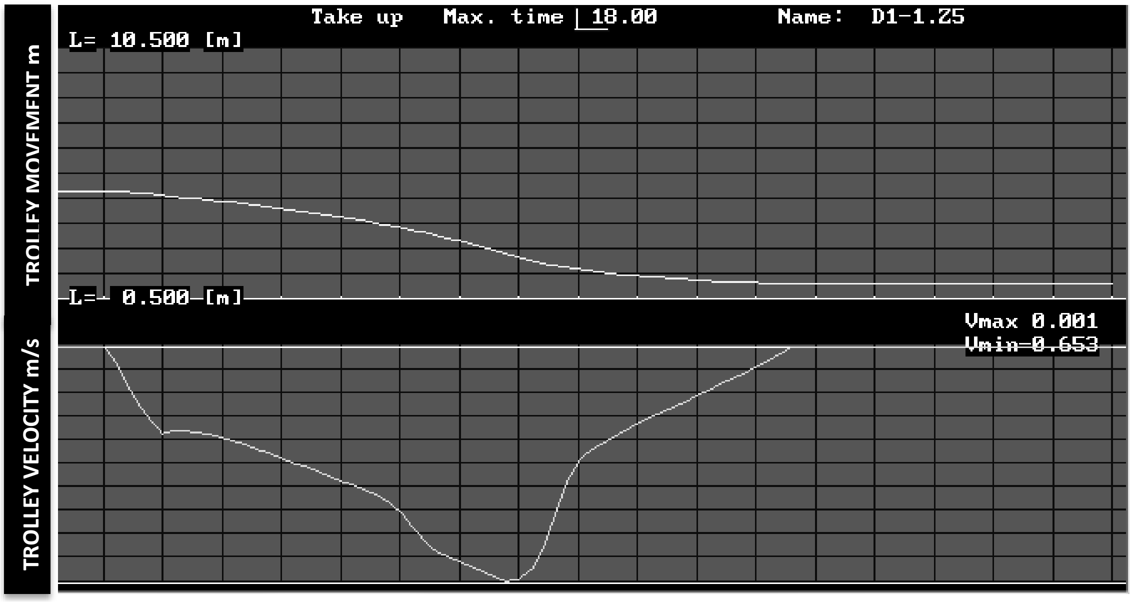

Figure 10. Winch inactive, overload protection (slip clutch) installed – set at 68.5 kN. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

The influence of changed tension limits on the conveyor performance were tested in a separate set of simulations. As stated earlier, upper limit was reduced by 50% to 68.5 kN (2 x 34, 25 kN of belt tension). The results are presented in Figures 9 and 10.

The following can be observed:

- The overload protection system reacts instantly to the rise of belt tension as a result of power shut down
- At its peak the trolley reaches a speed of 0.653 m/s (Figure 10, blue line) almost reaching its end of travel position (yellow line)
- Belt tension at the take-up and the head (red and blue lines) is maintained at a pre-set level but at the same time low tension of 6.1 kN is seen at the tail end (green line).

From the above it may be concluded that the limit has been set too low in this case and most likely the take-up will crash into the end-of-travel structure during aborted start.

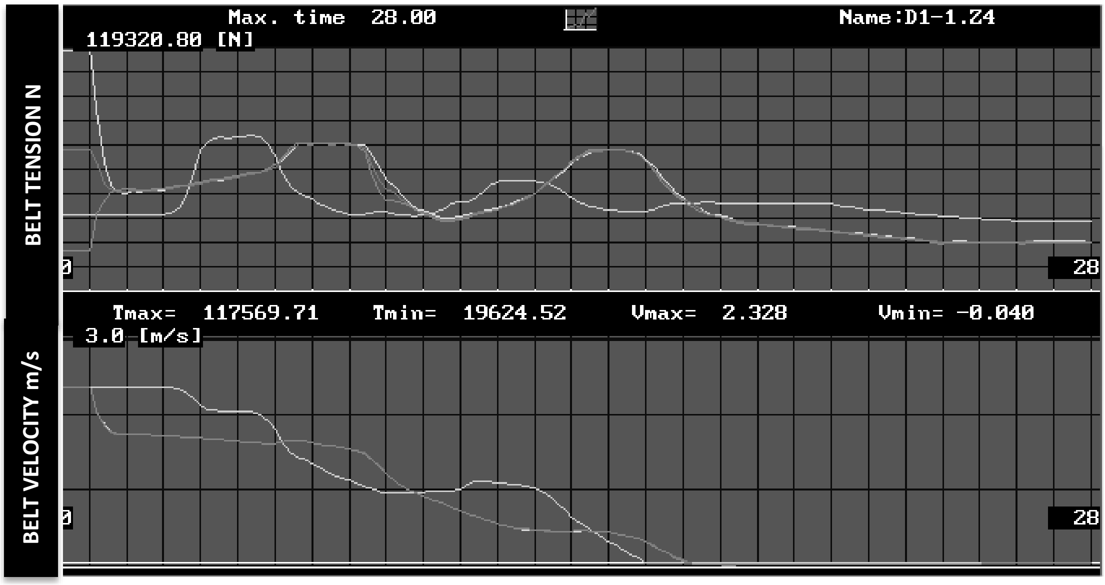

Figure 11. Winch active DOL – constant speed winch operation, overload protection (slip clutch) installed – set at 137 kN. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

Figure 12. Winch active DOL – constant speed winch operation, overload protection (slip clutch) installed – set at 137 kN. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

Figures 11 and 12 show the results of simulations where both the winch and the high load protection (slip clutch) are active.

As a result of the winch action, the slip clutch reacts only once (Figure 12, blue line) to the tension rise i.e. at the initial tension spike (Figure 11, flat top of the pink line). While the tension oscillations have not been eliminated, their peak values have been reduced. Once again the winch pays out belt for some time after the conveyor has stopped.

4.2 Conveyor Start Up

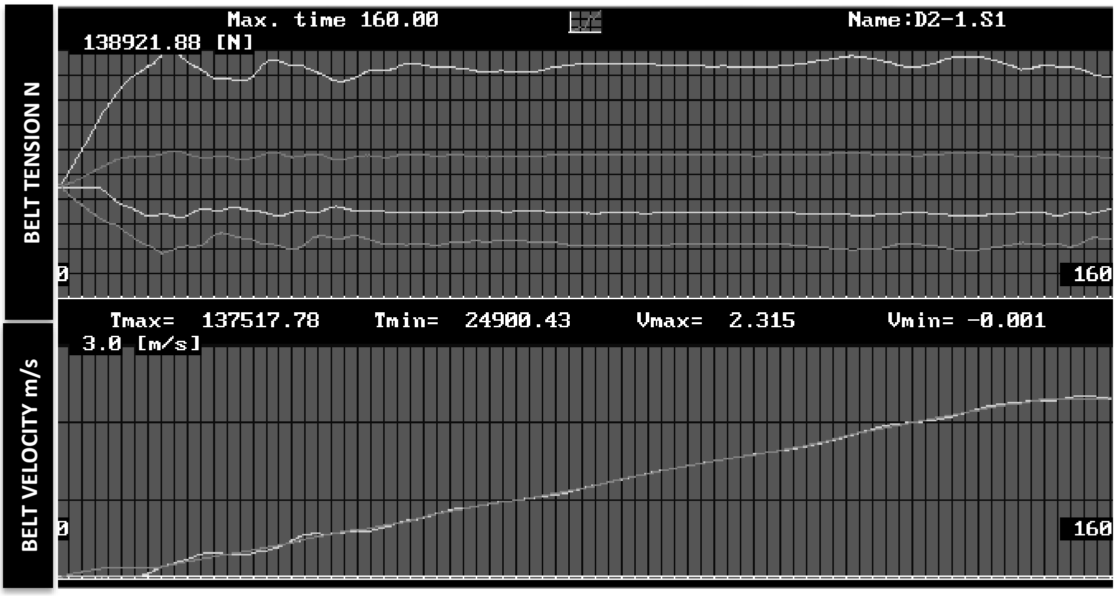

Figure 13. Fixed winch operation. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

Figure 13 shows graphs of belt tension and velocity during start-up with the inactive winch take-up. This simulation followed normal stop simulation as depicted by Figure 4.

It may be noted that dynamic effects are limited to the initial 50 seconds of the acceleration.

Figures 14 and 15 below present the results of conveyor start-up simulation with the take-up winch being powered during full start-up cycle. This simulation followed normal stop simulation as represented by Figures 5 and 6.

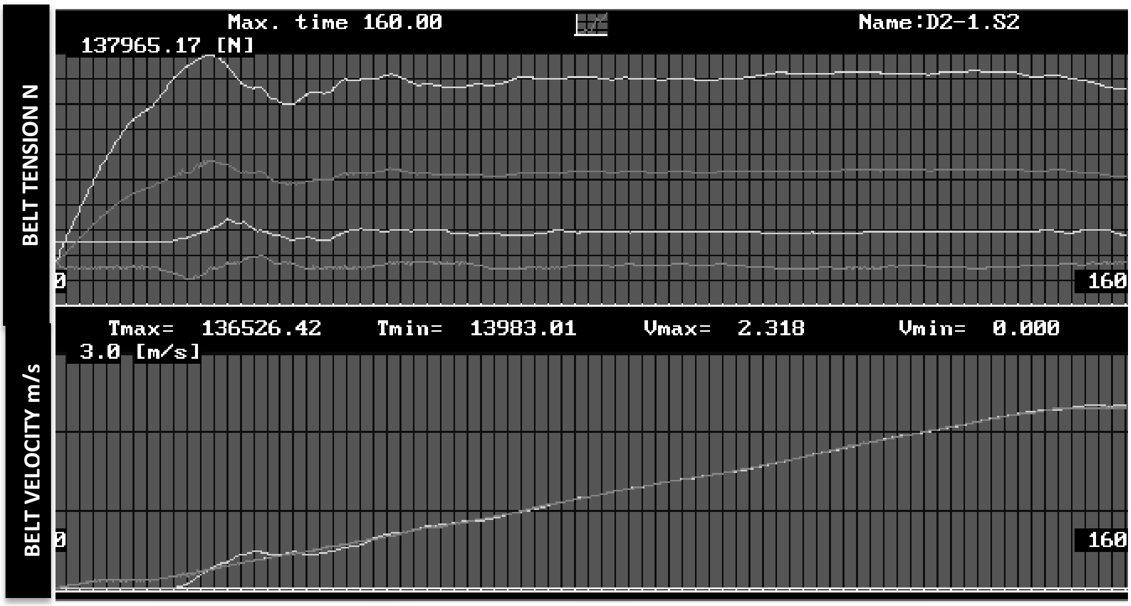

Figure 14. Winch active DOL – constant speed winch operation; trolley moving at 0.06 m/s. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

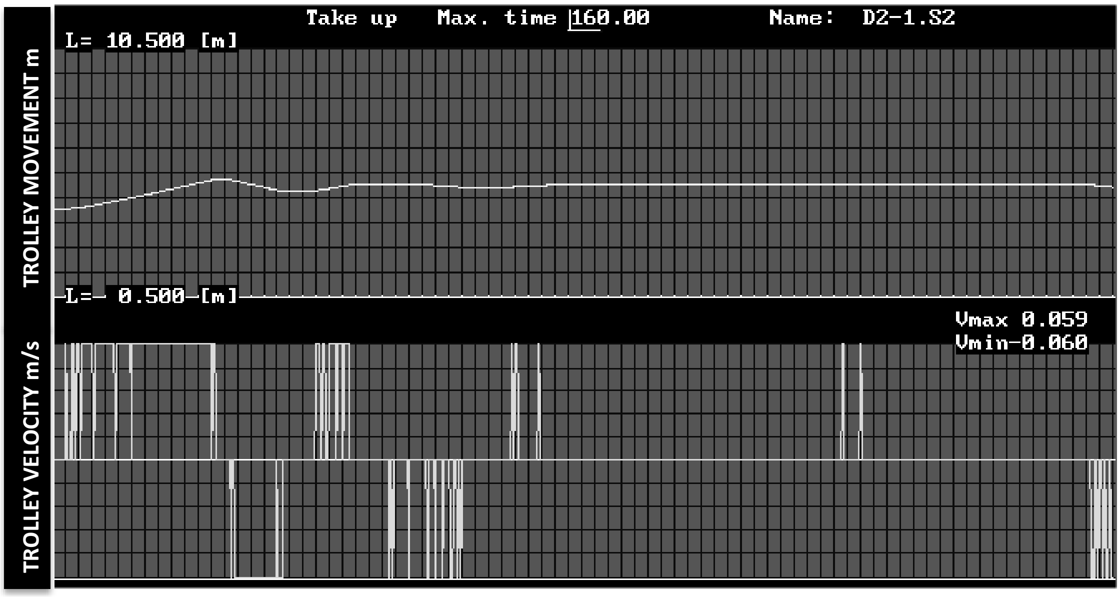

Figure 15. Winch active DOL – constant speed winch operation, trolley moving at 0.06 m/s. Graphs of take-up trolley movement [m] (upper) and take up trolley velocity [m/s] (lower)

The following observations can be made:

- While the winch responds to the belt, tension drops almost instantly and it is not able to maintain the set belt tension

- 24 seconds after commencement of the start-up, tension at the take-up drops to approximately 12.8 kN (Figure 14, red and pink lines) and fully developed drive pulley slip can be detected
- Once the dynamic effects diminish, the winch comes on in short 'bursts' to keep belt tension within set limits of about 2 kN (Figure 15, blue line).

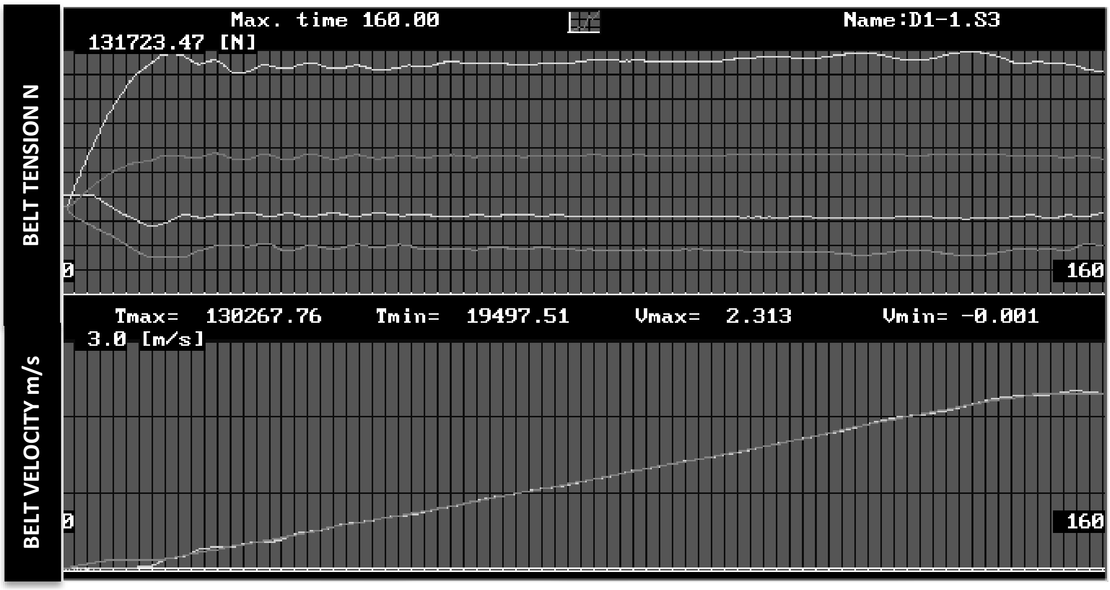

Figure 16. Winch inactive, low tension protection (hydraulic cylinder) installed. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

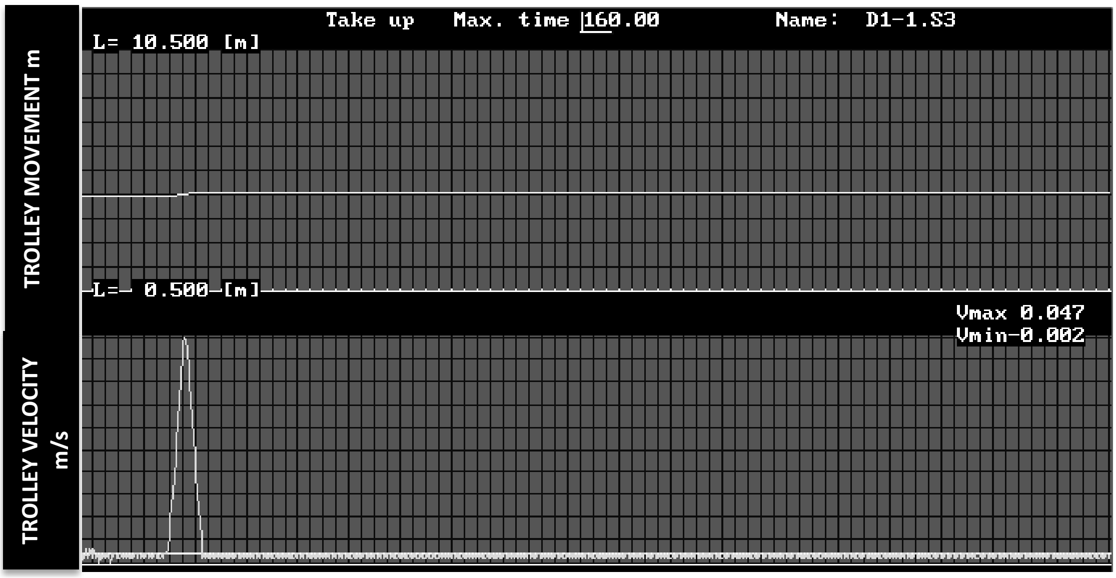

Figure 17. Winch inactive, low tension protection (hydraulic cylinder) installed. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

Figures 16 and 17 show the results of the start-up simulation with the inactive take-up winch but fitted with a low tension protection system (hydraulic cylinder). The low tension limit was set at 41.4 kN (2 x 20.7 kN of belt tension). This simulation follows the stopping sequence as depicted by Figures 7 and 8.

The following observations can be made:

- Action of the cylinder prevents significant belt tension drop (minimum reached is 19.3 kN) as can be seen in the flat section of the tension pink line (Figure 16)
- Action of the cylinder is reflected in a short spike of trolley velocity as seen on Figure 17 (blue line).

Figures 18 and 19 show the results of the start-up simulation with the take-up winch being inactive but fitted with a low tension protection system (hydraulic cylinder). Low tension limit has been increased to 47.4 kN (2 x 23.7 kN of belt tension). This simulation follows the stopping sequence as depicted by Figures 9 and 10.

The following observations can be made:

- Action of the cylinder prevents belt tension drop (minimum reached is 22.1 kN just after the secondary drive pulley) as can be seen in the flat section of the red line (Figure 18)
- Action of the cylinder is reflected in a prolonged spike of trolley velocity as seen on Figure 19 (blue line)
- Total trolley movement during early phases of the start-up is 2.0 m and may exhaust total available stroke of the cylinder.

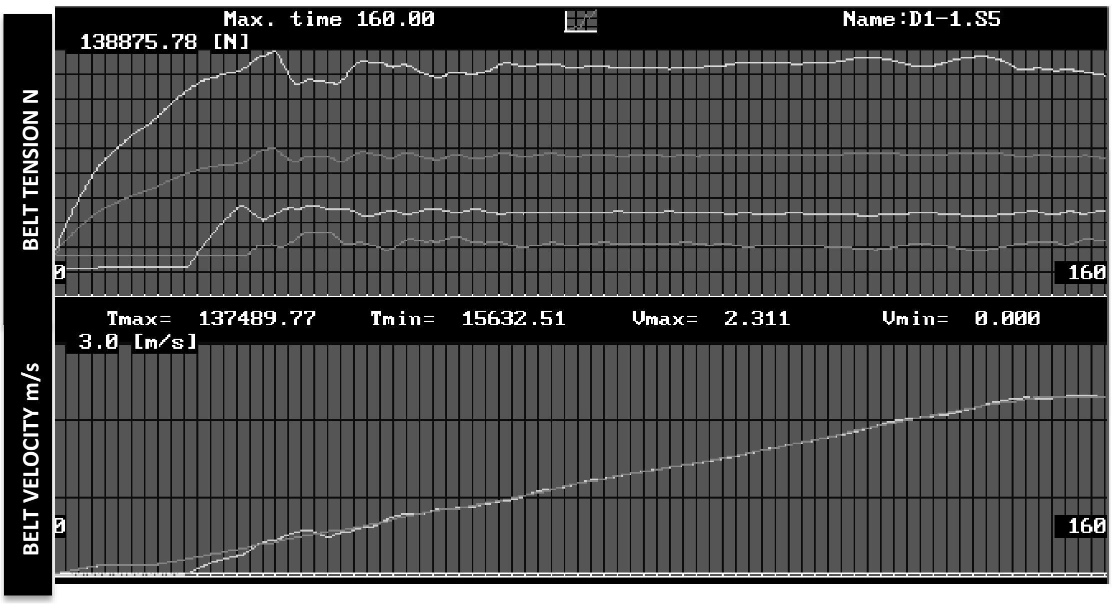

Figure 18. Winch inactive, low tension protection (hydraulic cylinder) installed. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

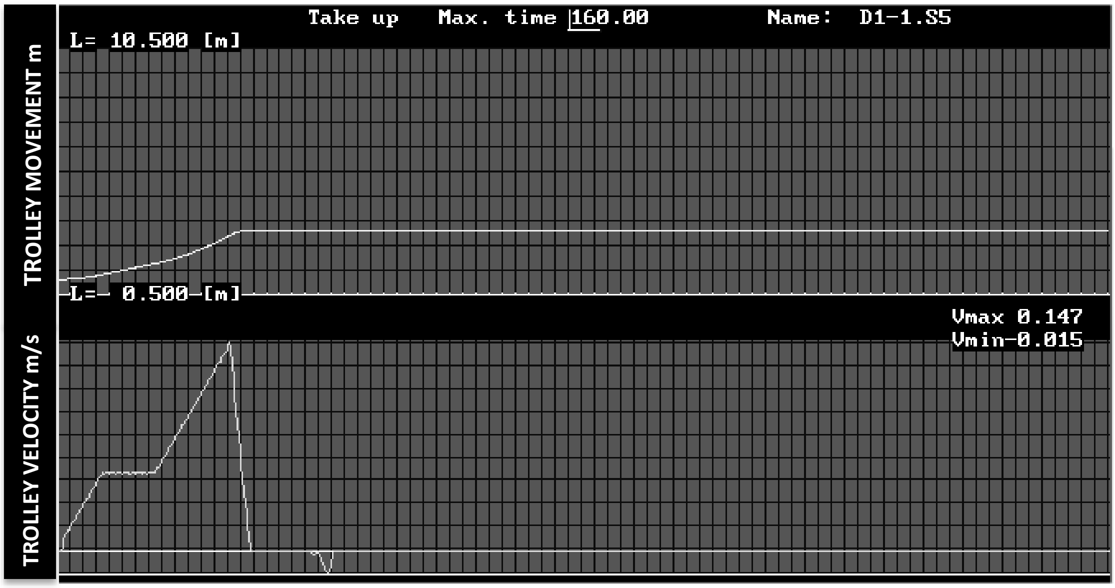

Figure 19. Winch inactive, low tension protection (hydraulic cylinder) installed. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

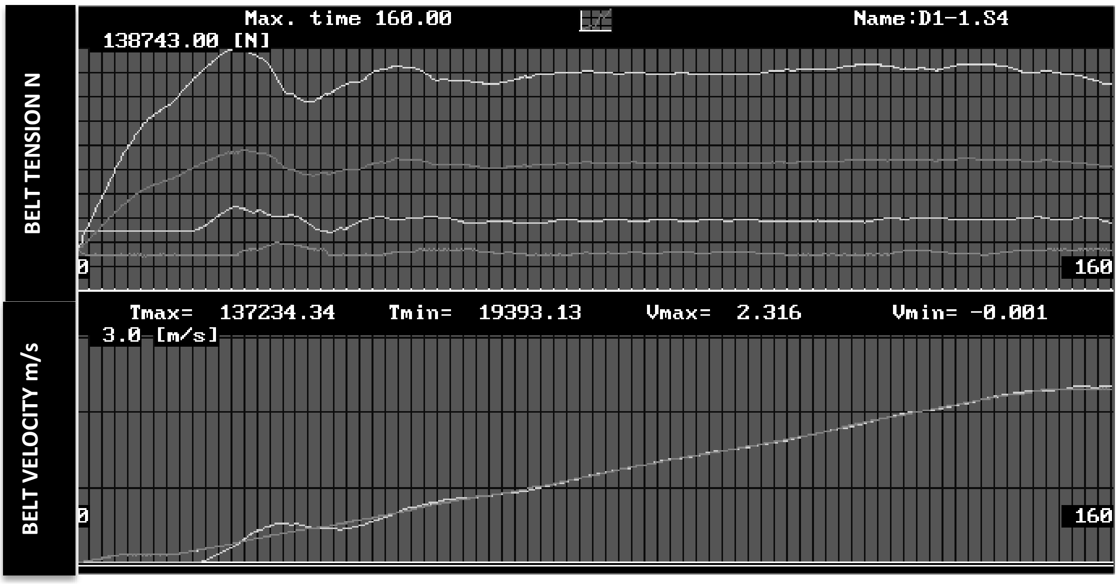

Figure 20. Winch active DOL – constant speed winch operation, take-up trolley speed 0.6 m/s, low tension protection (hydraulic cylinder) installed. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

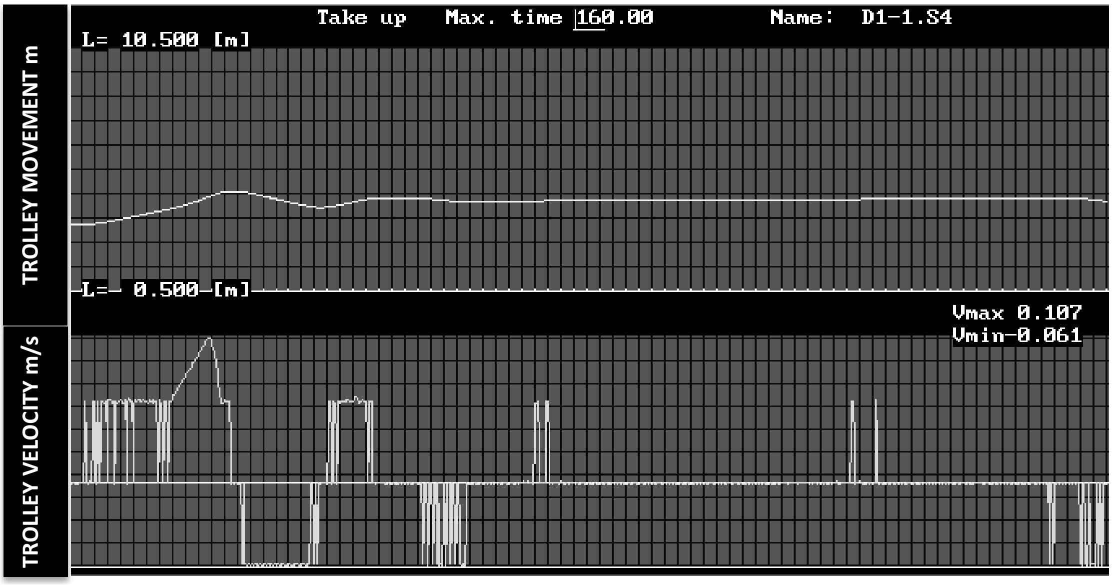

Figure 21. Winch active DOL – constant speed winch operation, take-up trolley speed 0.6 m/s, low tension protection (hydraulic cylinder) installed. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

The results of the simulation combining both the action of the winch and low tension protection system (hydraulic cylinder) are represented by Figures 20 and 21.

The following comments apply:

- Most of the corrective action is performed by the electric winch – both increasing and decreasing belt tension
- The hydraulic cylinder is activated only once, towards the end of the initial phase of the start-up when maximum torque is developed by both drives.

4.2 Aborted Start Up

Note: In all simulated cases motors were de-energised at the 101st second of the start-up sequence.

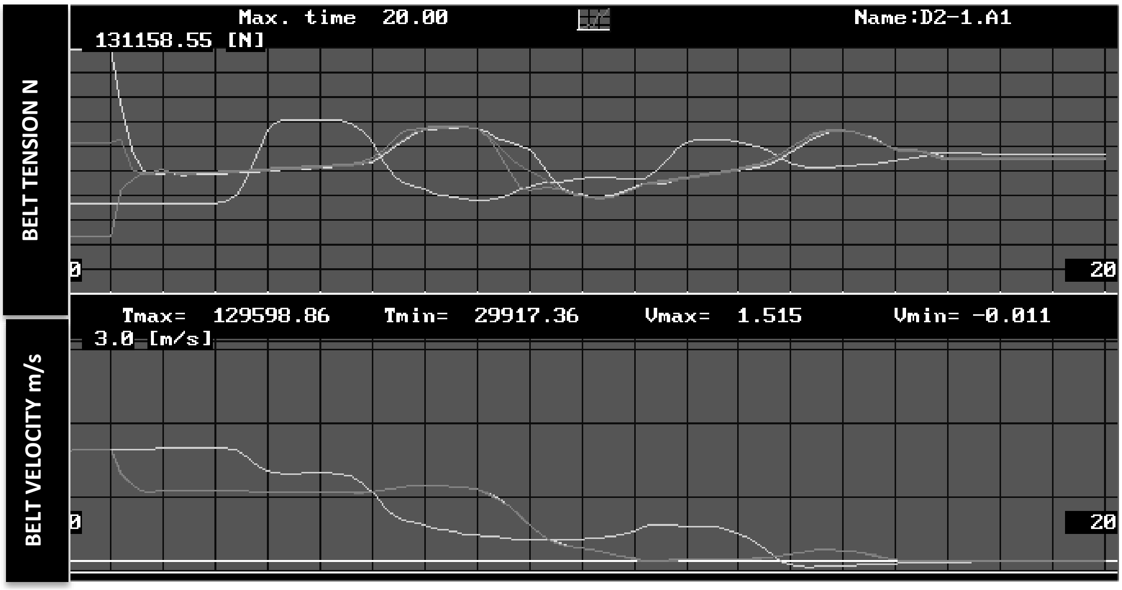

Figure 22. Fixed winch operation. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

Figure 22 shows results of the base case simulation, that is, aborted start with the winch being inactive. Dynamic response of the conveyor is similar to the normal stop case (Figure 4).

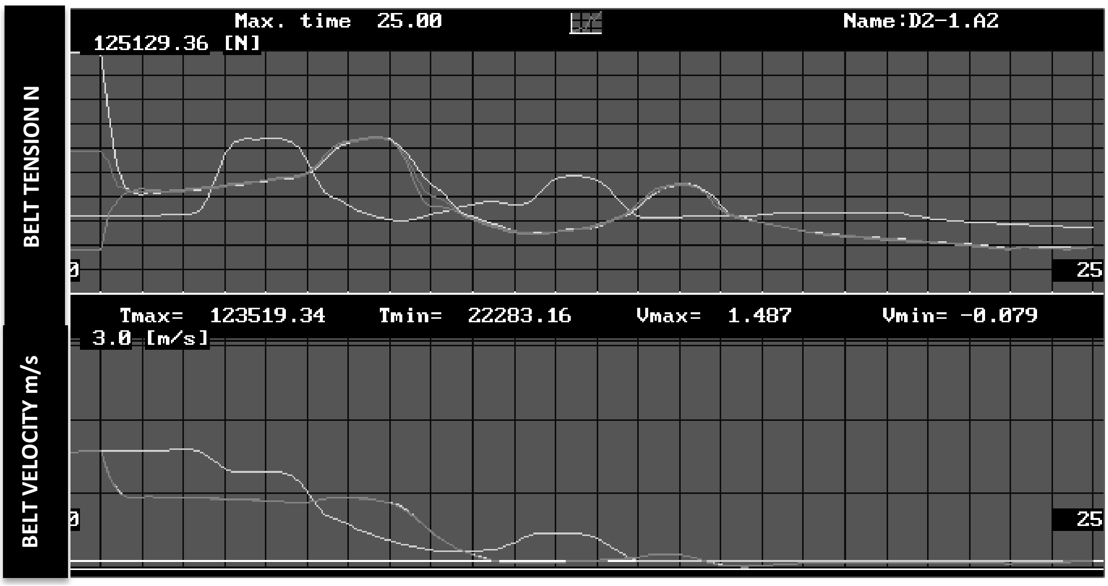

Figure 23. Winch active DOL– constant speed winch operation, trolley moving at 0.06 m/s. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail green), head (blue), after drive pulley T2 (red), take-up (pink)

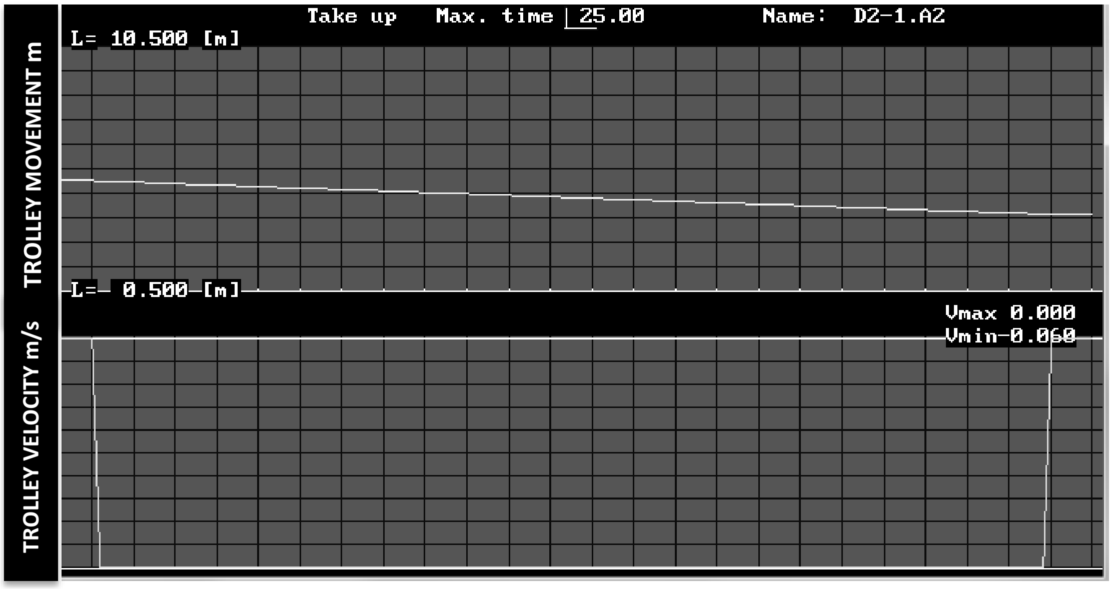

Figure 24. Winch active DOL – constant speed winch operation, trolley moving at 0.06 m/s. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

Figures 23 and 24 show the simulation result when the take-up winch remains active once the drives are de-energised. As a result, the take-up trolley continuously moves while paying out the belt.

The results can be summarised as follows:

- While the winch attempts to maintain pre-set tension, its speed is too low and as a consequence, oscillation of belt tension can be noted in a similar pattern to the fixed winch case (compare Figures 23 and 22)
- The winch remains active (Figure 23, pink line and Figure 24, blue line) after the conveyor has stopped, bringing head end belt tension to the pre-set level.

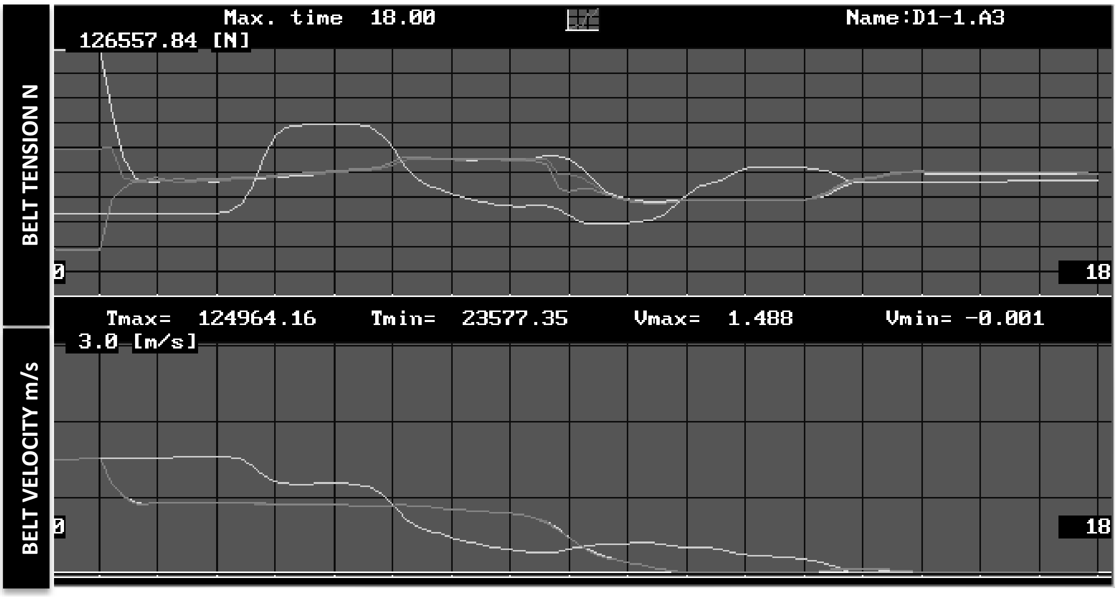

Figure 25. Winch inactive, overload protection (slip clutch) installed. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head **(**blue), after drive pulley T2 (red), take-up (pink)

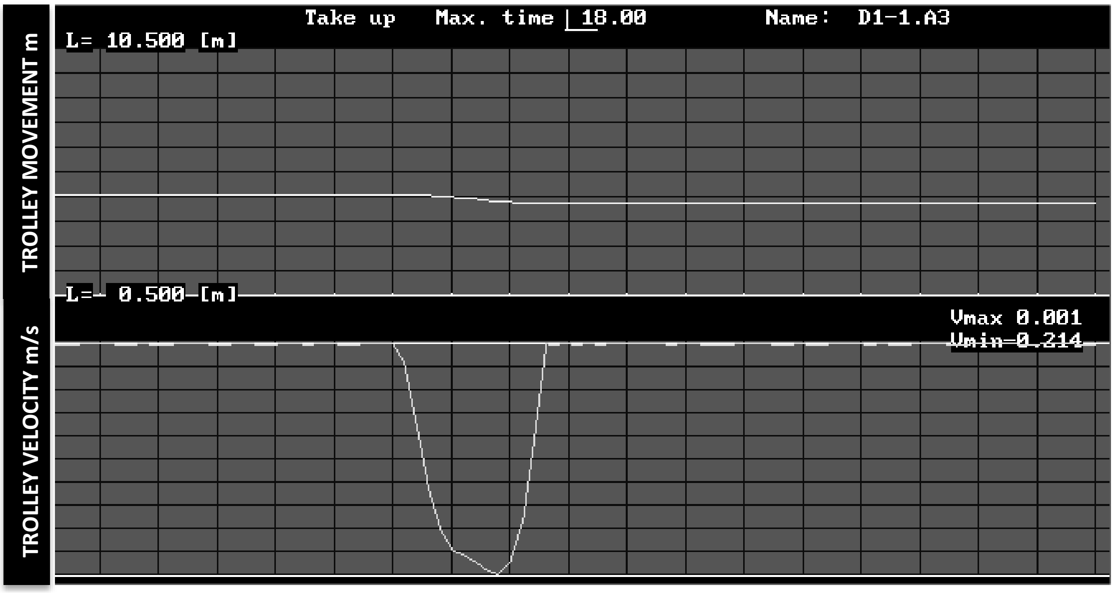

Figure 26. Winch inactive, overload protection (slip clutch) installed. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

The Influence of the overload protection system, while the winch remains inactive, is presented by Figures 25 and 26. As stated in Paragraph 3.4, the overload limit was set at 137 kN of total pull at the take-up trolley (2 x 68.5 kN belt tension).

The following can be observed:

- For approximately six seconds after the drives have been de-energised, the pattern of belt tension and velocity change is identical with the fixed take-up system
- The overload protection system comes into action when the tension limit is reached after six seconds and its action is manifested by a flat top belt tension pattern at the head end of the conveyor (Figure 25, blue, red and pink lines, also compare with Figure 22)
- Overload protection systems action is reflected in the trolley movement as shown by Figure 26 (blue line, first trolley velocity spike at max. of 0 214 m/s).

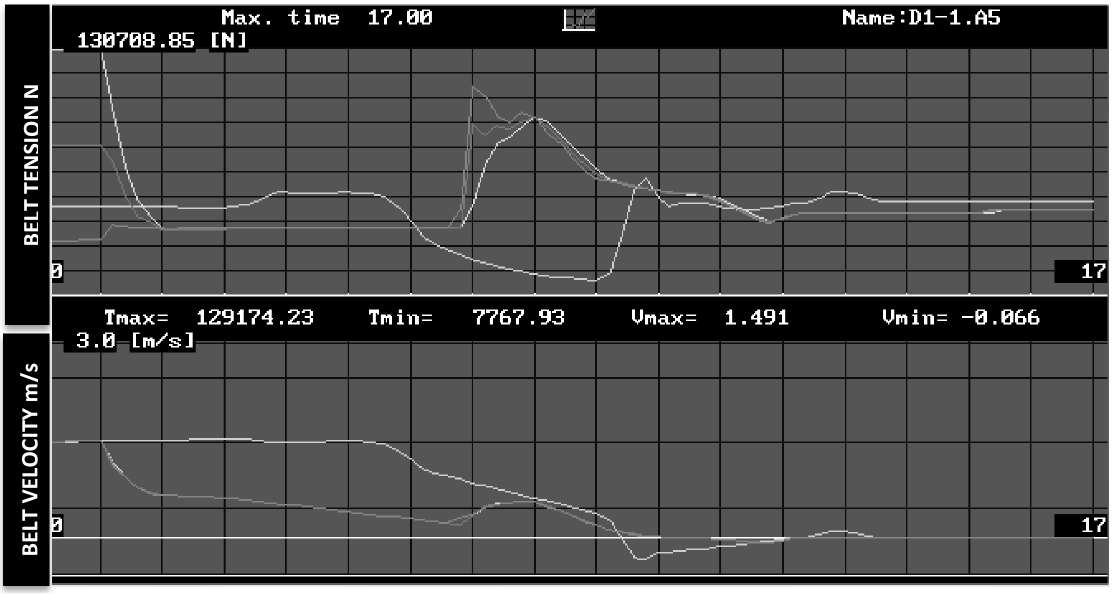

Figure 27. Winch inactive, overload protection (slip clutch) installed – set at 68.5 kN. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), take-up (red)

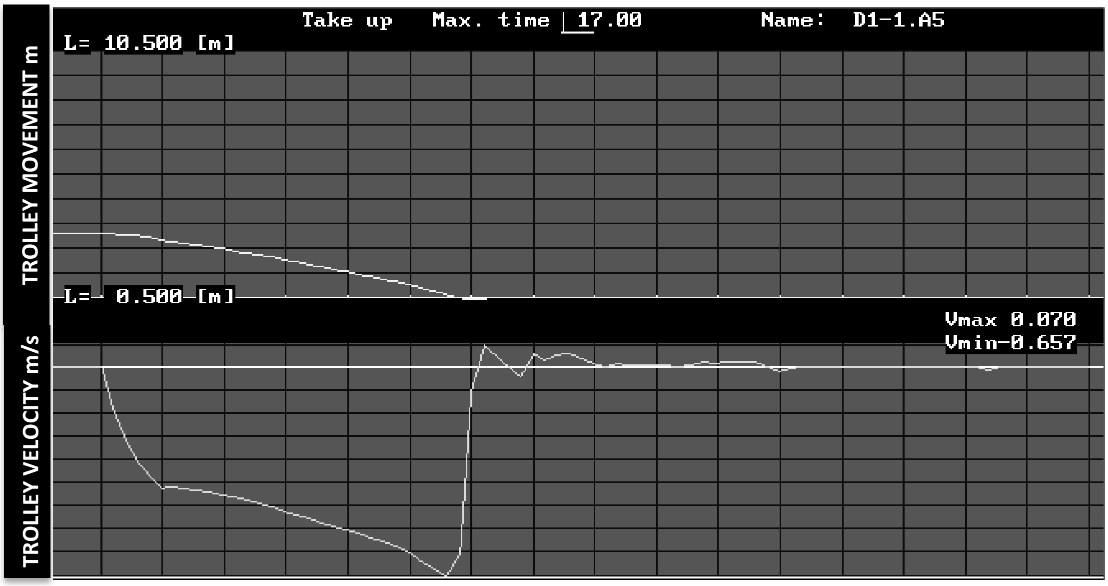

Figure 28. Winch inactive, overload protection (slip clutch) installed – set at 68.5 kN. Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s] (lower)

Influence of changed tension limits on the conveyor performance were tested in a separate set of simulations. As stated earlier, upper limit was reduced by 50% to 68.5 kN (2 x 34.25 kN of belt tension). The results are presented by Figures 27 and 28.

The following can be observed:

- The overload protection system reacts instantly to the rise of belt tension as a result of power shut down
- At its peak, the trolley reaches a speed of 0 657 m/s (Figure 28, blue line)
- In the sixth second after the power is cut off, the trolley reaches the end of travel limit and becomes locked in the structure (Figure 28, yellow line) resulting in a spike of belt tension at the head end (Figure 27, red and blue lines)
- At the same time, low tension of 7.7 kN can be noted at the tail end.

This development has its origins in the stopping sequence when the take-up trolley has moved almost to the end of the travel limit. Subsequent trolley movement during early stages of acceleration was significantly lower and did not provide sufficient compensation. Overall, the simulation underlines the importance of a proper assessment of the tension limits, taking into account performance of a conveyor during various stages of operation.

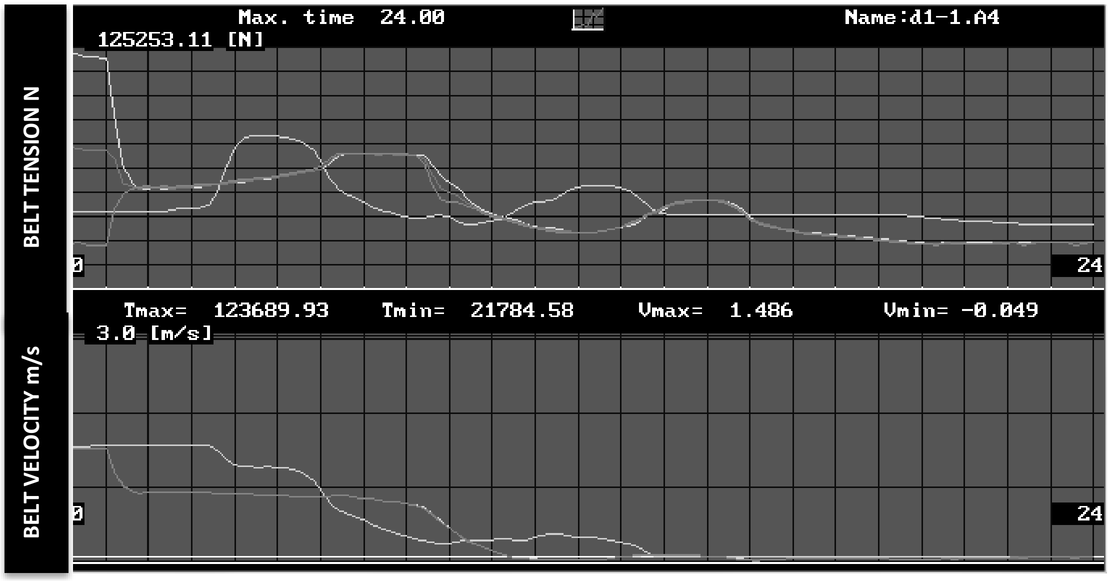

Figure 29. Winch active DOL – constant speed winch operation, overload protection (slip clutch) installed – set at 137 kN (total pull at the trolley). Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive pulley T2 (red), take-up (pink)

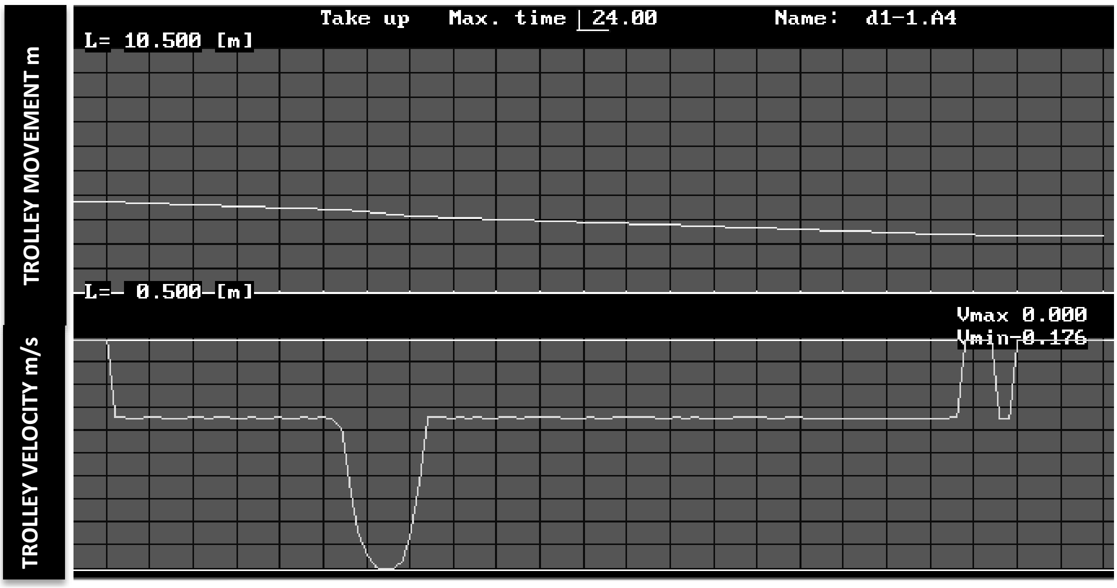

Figure 30. Winch active DOL – constant speed winch operation, overload protection (slip clutch) installed – set at 137 kN (total pull at the trolley). Graphs of take-up trolley movement [m] (upper) and take-up trolley velocity [m/s](lower)

Figures 29 and 30 show the results of simulations where both the winch and the high load protection (slip clutch) are active.

As a result of the winch action, the slip clutch reacts only once (Figure 30, blue line) to the tension rise that is, at the initial tension spike (Figure 29, flat top of the blue, red and pink lines).

Tension oscillations have not been eliminated, but their peak values have been reduced.

Once again the winch pays out belt for some time after the conveyor has stopped.

5. RESULTS OF THE SIMULATION – VFD WINCH OPERATION

5.1 Conveyor Stop

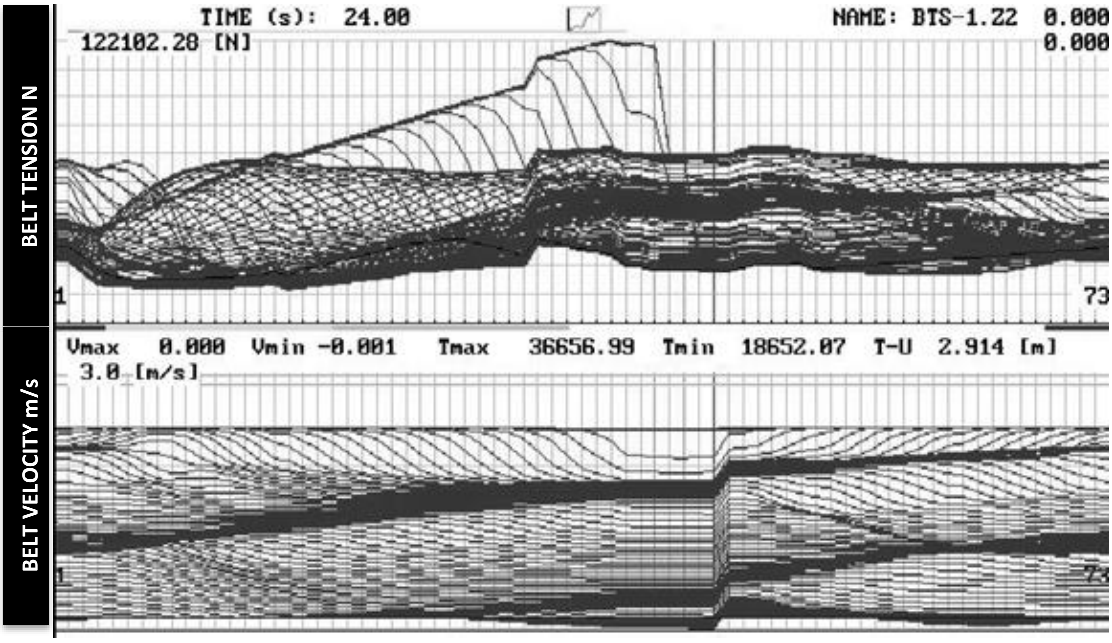

Figure 31. Full load conveyor stop. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) along the conveyor

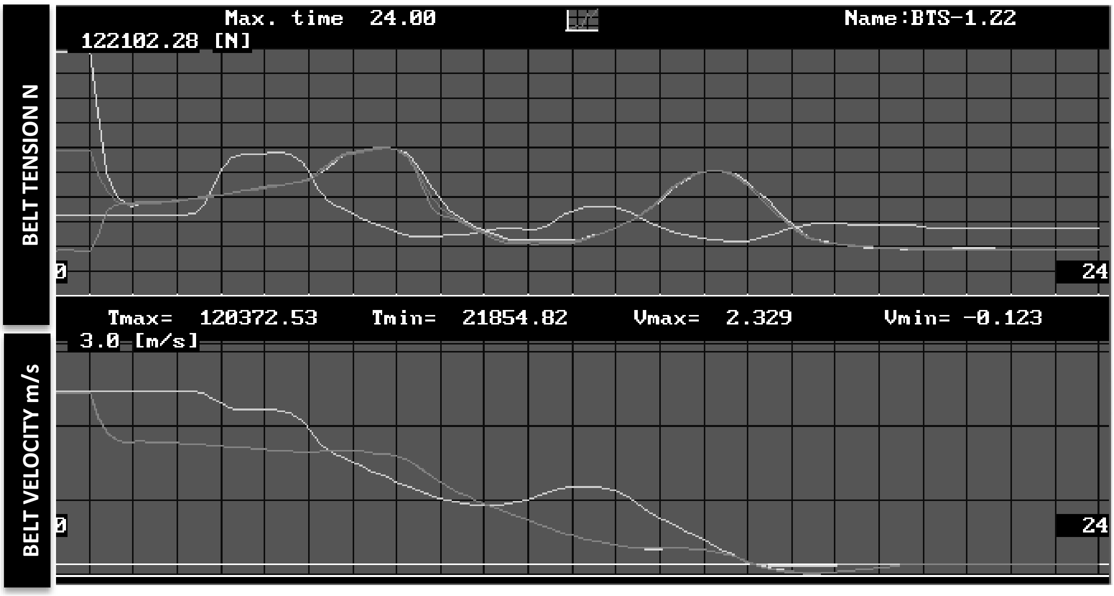

Figure 32. Full load conveyor stop. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive (red), take-up (pink)

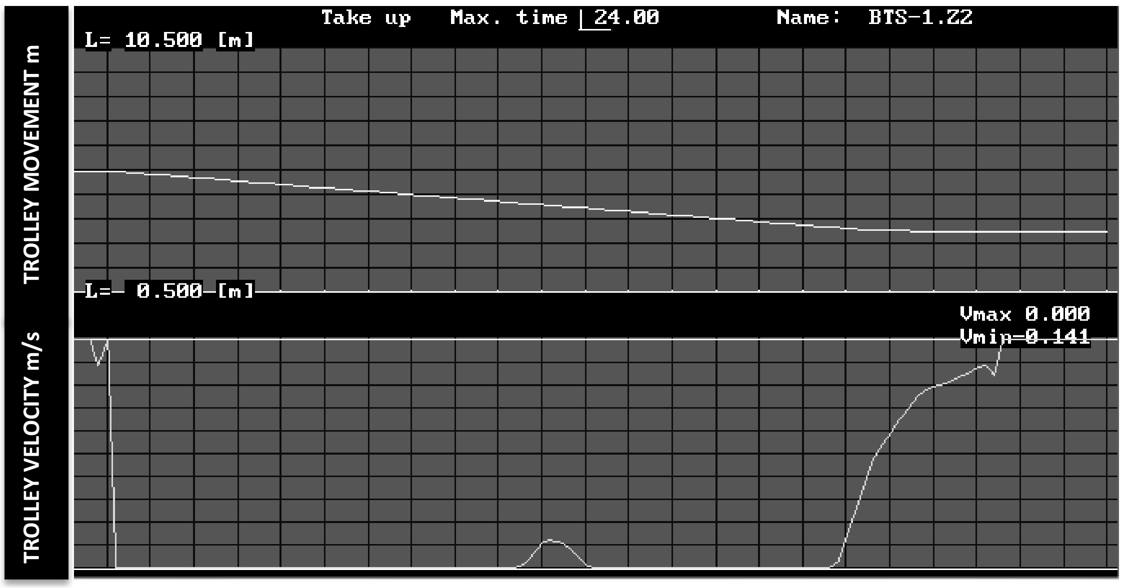

Figure 33. Full load conveyor stop. Graphs of take-up trolley travel [m] (upper) and take-up trolley velocity [m/s] (lower) along the conveyor

Figures 31, 32 and 33 present simulation results of a conveyor loaded stop.

The following observations can be made:

- Due to the take-up trolley speed limit imposed and consequent retarding action by the VFD, trolley travel has been limited and low belt tension zones (minimum tension 14.1 kN) are not evident (see Figure 31, also green line of Figure 33)
- The introduced control changes show belt tension changes which are now a combination of automatic take-up action and fixed system as reflected by two distinct tension spikes on Figure 32
- Maximum trolley speed is 0.141 m/s and remains at that level for a significant period of time.

Note: Nominal take up tension is set at 21.7 kN.

5.2 Conveyor Start Up

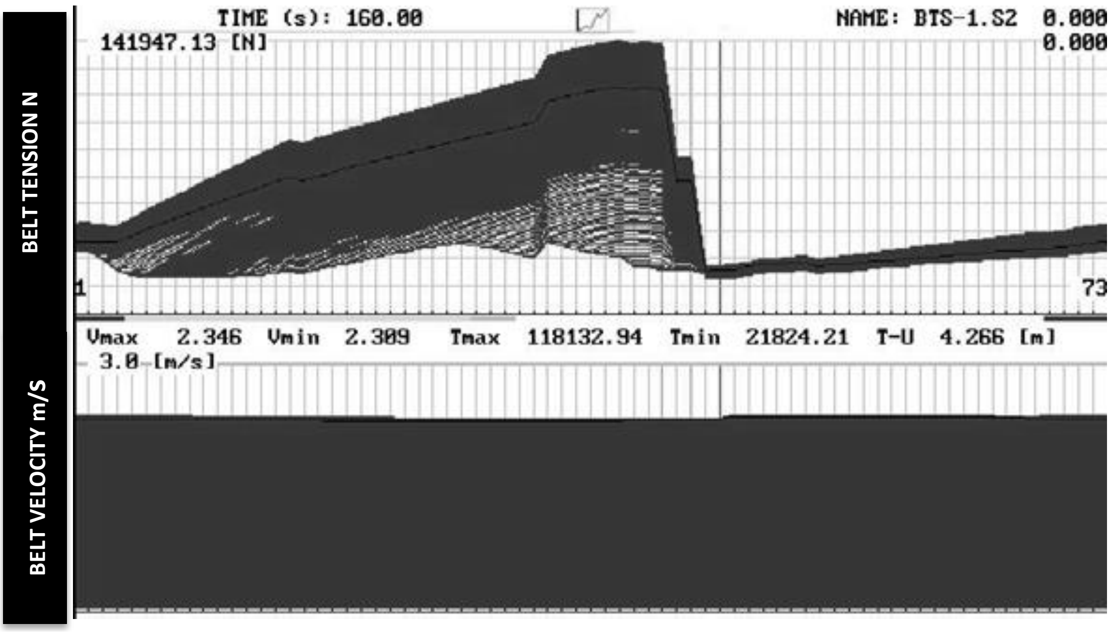

Figure 34. Full load conveyor start-up. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) along the conveyor

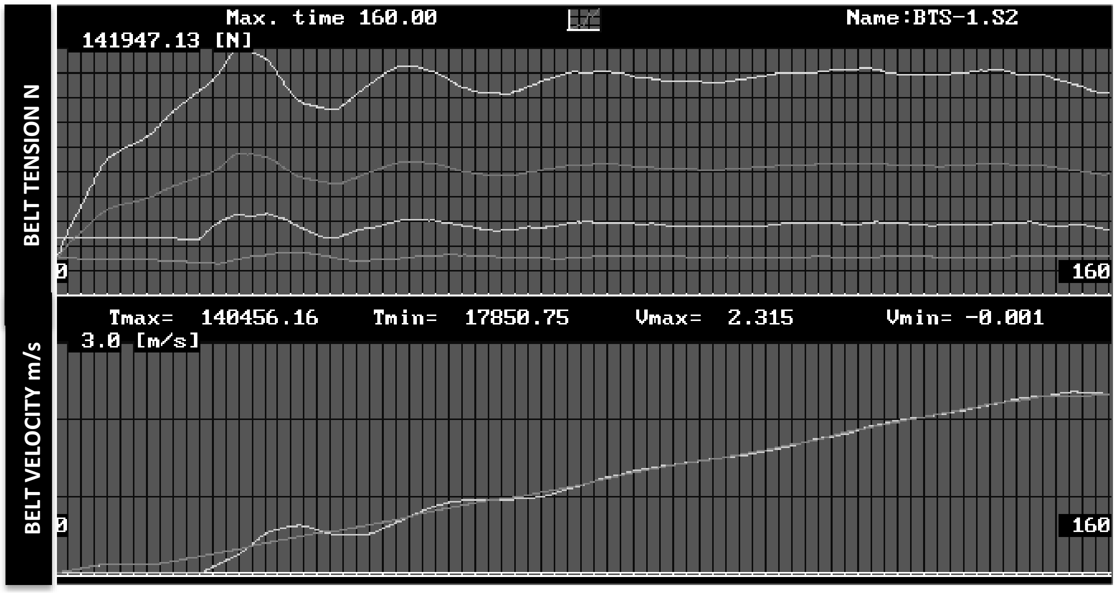

Figure 35. Full load conveyor start-up. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive (red), take-up (pink)

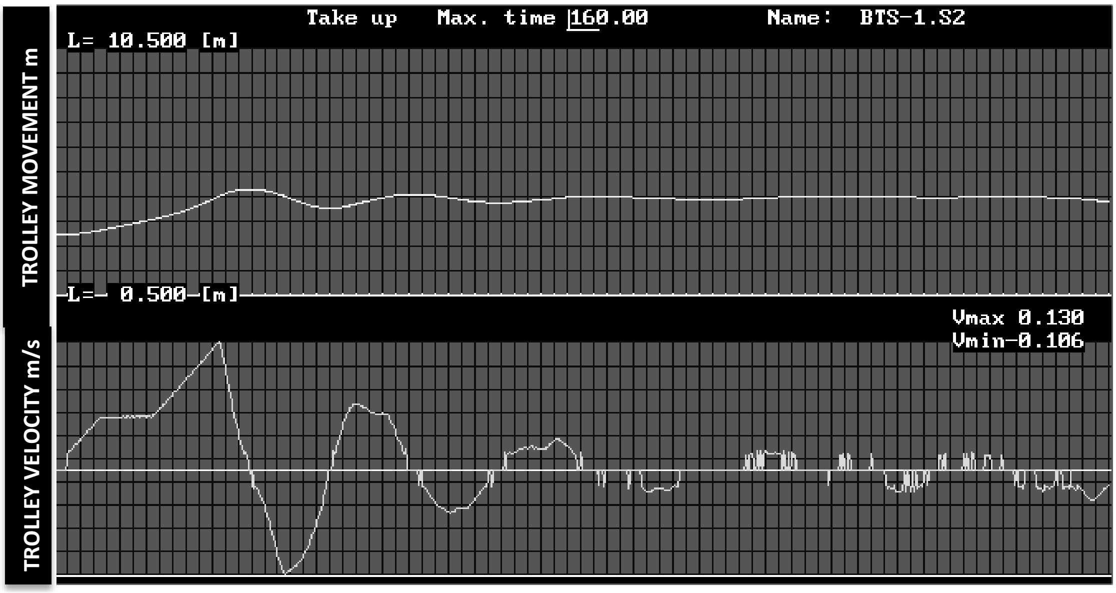

Figure 36. Full load conveyor start up. Graphs of take-up trolley travel [m] (upper) and take-up trolley velocity [m/s] (lower) along the conveyor

5.3 Aborted Start-Up

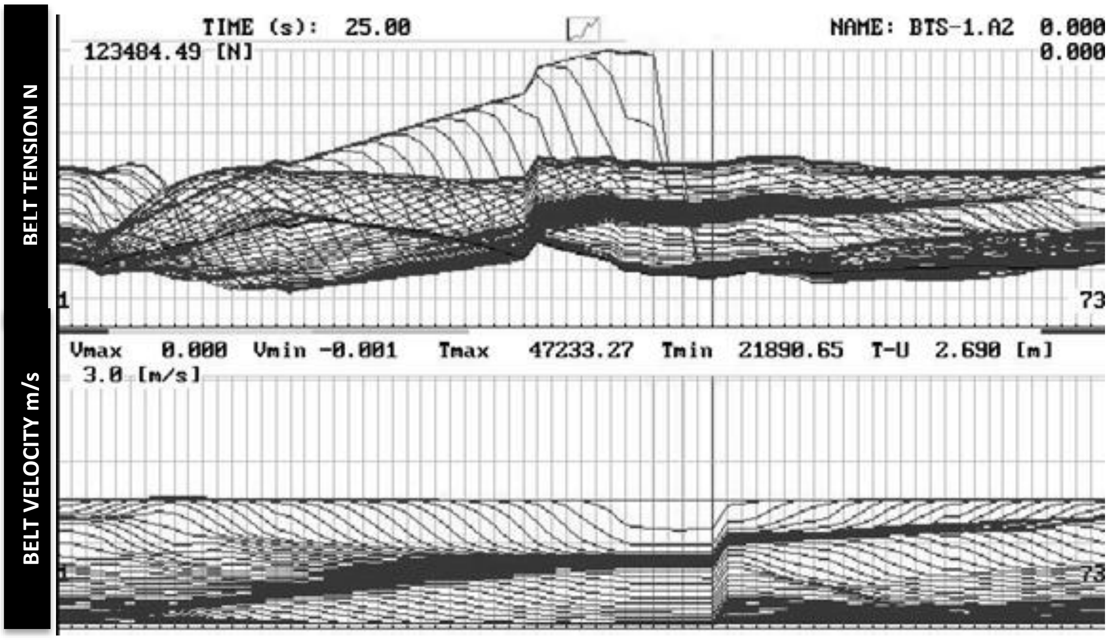

Figure 37. Full load conveyor aborted start-up. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) along the conveyor

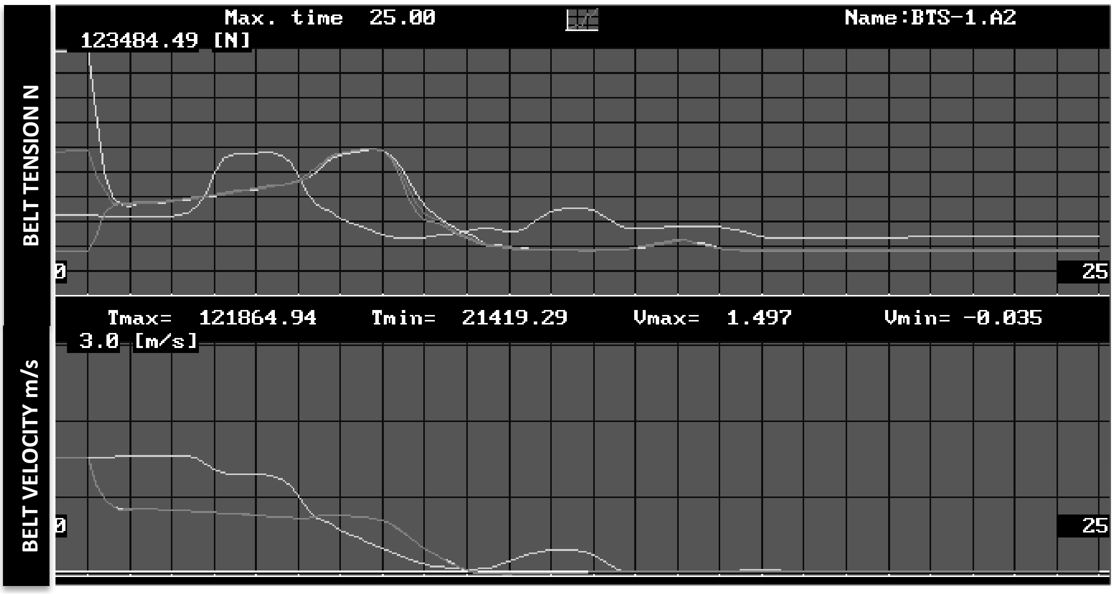

Figure 38. Full load conveyor aborted start-up. Graphs of belt tension [N] (upper) and belt velocity [m/s] (lower) at tail (green), head (blue), after drive (red), take-up (pink)

Figure 39. Full load conveyor aborted start-up. Graphs of take-up trolley travel [m] (upper) and take up trolley velocity [m/s] (lower) along the conveyor

Figures 37, 38 and 39 present simulation results of a loaded conveyor aborted start.

The following observations can be made:

- Due to the speed limit imposed and consequent retarding action by the variable frequency drive, take-up travel is limited in comparison with the Mode 1 case and consequently low belt tension zones (minimum tension 15.1 kN) are not evident (see Figure 37 and Figure 38)
- In a similar way to the loaded stop, due to trolley speed limitation pattern of tension, changes partly reflect automatic take-up action and partly fixed system – a distinct tension spike can be noted on Figure 38
- Maximum trolley speed is 0.141 m/s and remains at that level for a significant period of time, however, unlike the loaded stop there are two distinct periods when the trolley moves with maximum speed
- The take-up itself does not induce shock loads during operation.

Note: Nominal take-up tension is set at 21.7 kN

6. CONCLUSIONS AND RECOMMENDATIONS

- Simulation results show that the proposed concept is technically sound and is able to improve performance of a winch type take-up
- Proper settings of the tension limits (both high and low) are critical to the successful operation of the system. If this is done on a 'rough estimation' basis,

substandard performance and even accidents, shown by the simulations, can be expected.

Two possible scenarios should be taken into account:

- If the high tension protection is set too low, movements of the take-up trolley during any stop may exceed the take-up travel limits
- If the low tension limit is set too high, the hydraulic cylinder's stroke may be insufficient to provide the required compensation.

- Proper selection of a variable frequency drive system is of utmost importance.

The following should be considered:

- Range of trolley speeds/motor rpm (in most cases take-up will have at least a 2:1 ratio which means that any trolley movement will result in rope speed being a multiple of the trolley velocity)
- Torque requirements and torque variation in relation to the frequency.

7. HIGHLIGHTING THE MAIN ADVANTAGES

- An automatic winch system is more compact compared to gravity systems, especially underground
- The system is adaptable if sized correctly so that the tensions and speeds can be adjusted to suit belt extensions or changes if compared to gravity systems. No hardware changes are required
- Using the variable frequency drive not only offers better control as described, but also decreases maintenance on most conveyor and take-up equipment and increases belt life
- The system is versatile and components can be selected as per requirements. Not all components are necessary for every belt and will depend on conveyor data to determine correct selection.

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