CASE STUDY: ADVANCEMENTS IN OVERLAND CONVEYOR TECHNOLOGIES

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ABSTRACT

This paper will highlight several recent overland conveyor systems and some of the latest innovations in overland conveyor technology. The Shondoni 21 km overland conveyor will be discussed. This is the longest single flight conveyor system in the world without an intermediate drive station. The 21,000 t/h Carajás Serra Sul S11D overland conveyor system in Brazil will also be discussed. The total system length is 9.5 km with the largest conveyor utilising a ST-8000 N/mm belt. It has an astonishing 3,610,000 N-m braking torque distributed over a total of seven brakes. Both the belt rating and installed braking torque are currently the world's largest in operation. Design principles, construction, and field measurements for both of these will be discussed.

1.0 INTRODUCTION

As the world's demand for raw materials grows, so does the need for new mining technologies and bulk materials handling innovations. The continuing evolution of the time-tested and dependable overland conveyor is no exception. Over the past 40 years the technology behind these machines has progressed in a steady and methodical manner.

The continuing need to push the limits of technology, while clinging to the historically tried and true design rules, is a balancing act that designers continue to play. However, with each incremental advancement, conveyor technology has continued to evolve and shows no sign of slowing down.

2.0 SHANDONI OVERLAND CONVEYOR

The development of the 21 km overland conveyor for Sasol's Shandoni mine in South Africa has an interesting backstory. Sasol's Middelbult Colliery, which was currently supplying coal to the 600 mega watt power station in Secunda, was reaching the end of its lifespan. As part of Sasol's replacement programme, the Shandoni mine was selected to replace this supply. However, the Shandoni mine is over 16 km from the power station (as the crow flies). Furthermore, there are several towns and villages in-between, as well as sensitive areas and other geographical obstacles. Clearly trucking coal over this distance was undesirable, costly, and highly intrusive to the surrounding area. Furthermore, this relatively short distance makes railway transportation and loading/unloading equally as cost prohibitive and unattractive. An overland conveyor, however, is uniquely suited for this type of challenge.

A plan view of the conveyor route is shown in figure 1. The route requires multiple horizontal curves to bypass several small communities and loop around the outer

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parameter and countryside. The resulting profile makes a "C" shape with the starting and ending angles almost 180 degrees to one another.

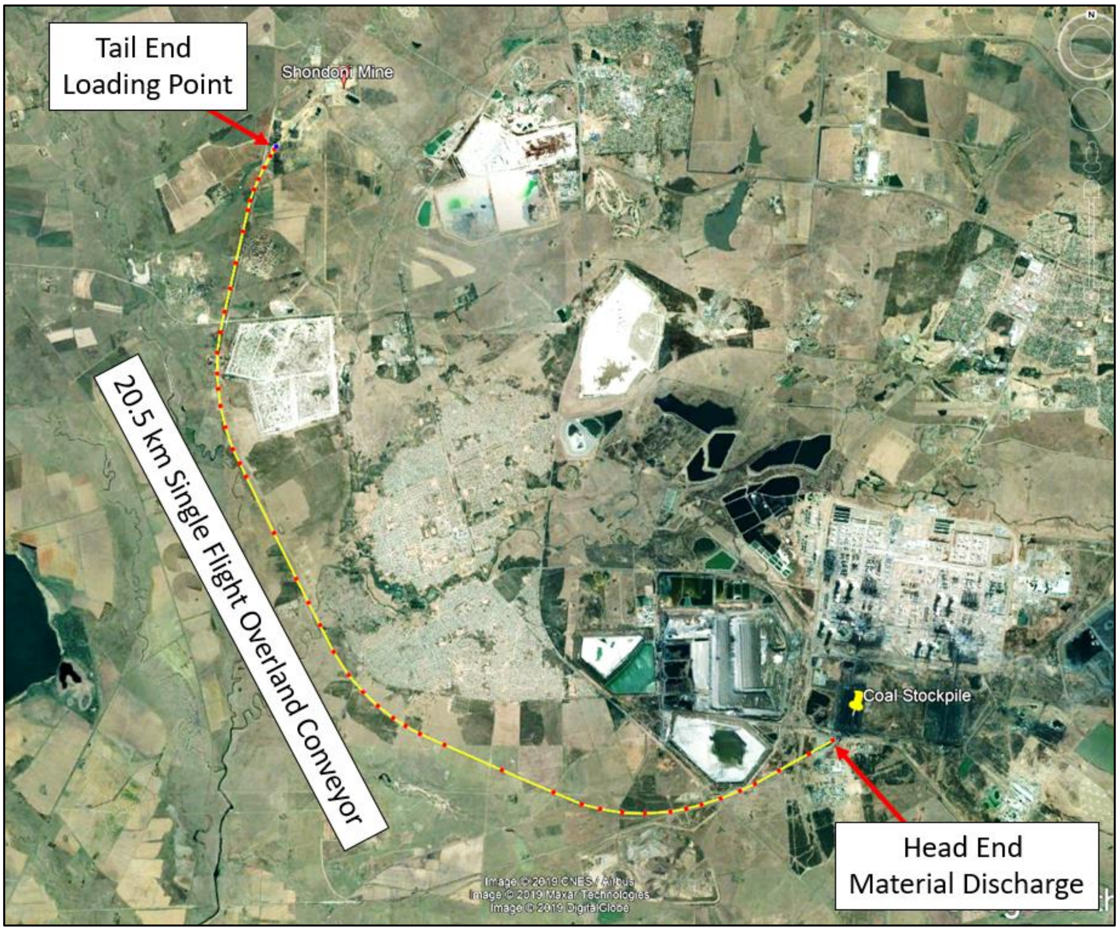

Figure 1. C-shaped conveyor profile for the 21 km Shandoni overland conveyor

Although the overall elevation change of the conveyor is almost zero, the profile drops over 60 m in in the first 10 km. Combined with 5 major horizontal curves, and numerous convex and concave vertical curves, the engineering and design of this system was far from ordinary. Figure 2 shows the profile of the conveyor and plethora of vertical and horizontal curves.

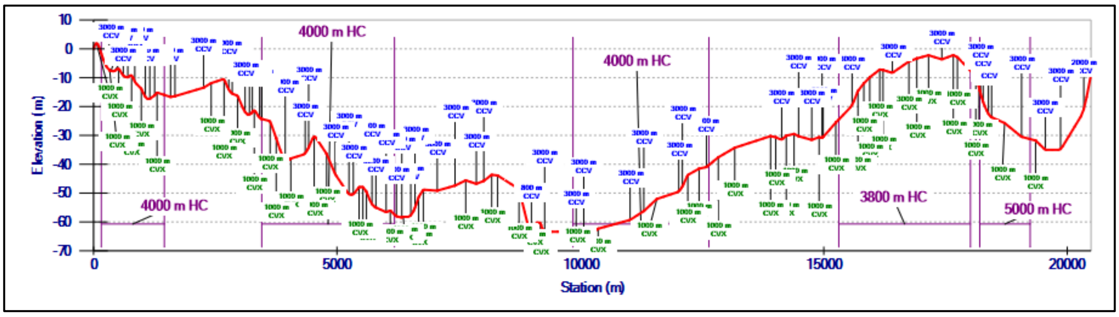

Figure 2. Conveyor profile and various horizontal and vertical curves.

After an extensive feasibility study had been completed, the conveyor system went out for bid as two separate overland conveyors. The two-conveyor option was considered quite reasonable and consisted of a 13.5 km and 7.0 km conveyor. The first conveyor required a belt rating of ST-2000 N/mm while the second required a ST-1500. Both conveyors would have utilised a 1200 mm belt running at 5.8 m/s.

However, a more cost competitive option that was analysed was the use of a booster drive midway along the conveyor. Booster drives are not new, and the evolution of VFD drives has made the starting and stopping control of these systems relatively easy to implement. Combing the two conveyors would have the advantage of eliminating a second take-up system and would result in a simpler less expensive transfer chute. These advantages could be obtained without sacrificing the belt rating or other major components when compared to two separate conveyors.

However, having an entire drive station in the middle of a 21 km belt conveyor is far from desirable. Drawbacks of such a design include:

Security - A booster drive station requires extra security as it is outside the common mining boundaries.

Maintenance – Having to lock out a separate drive station 10+ km from each end of the mine is both inconvenient and time consuming. This results in additional downtime.

Added transfer point – Even well-designed transfer chutes can be the cause for unwanted downtime and are the source of many conveyor problems. Even though a booster station would result in a simpler transfer chute design, there still exists the real possibility of transfer chute plugging, belt tracking, belt rip detection, and many other associated problems.

For these reasons a third option utilising a single flight (without any intermediate drives) was investigated. Material would be transported the entire 21 km without interruption.

As it turned out, the profile for this system lent itself beautifully to a single flight option. The required horizontal curve radii were within acceptable limits and, more importantly, the increased belt rating was quite minor.

The mid-station drive option required a ST-1600 N/mm belt rating. The single flight option only increased this to a ST-2500. This only required a small increase in cable diameter of the belt. Top & bottom covers remain the same, as does transportation and installation cost. As such when considering the cost of the entire system, the increased cost for the belt rating is substantially less than what would be required for other options such as a booster drive configuration. Furthermore, with the desired idler spacing, the lower rated ST-1600 belt resulted in concerns regarding the idler junction stress. The higher ST-2500 belt alleviated this issue which was another benefit.

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2.1 GENERAL DESIGN SPECIFICATIONS

In the end, the optimal final design resulted in a 1200 mm wide belt running at 6.5 m/s. A 45 degree carry side idler set was used. The cross-sectional loading profile is shown in figure 3.

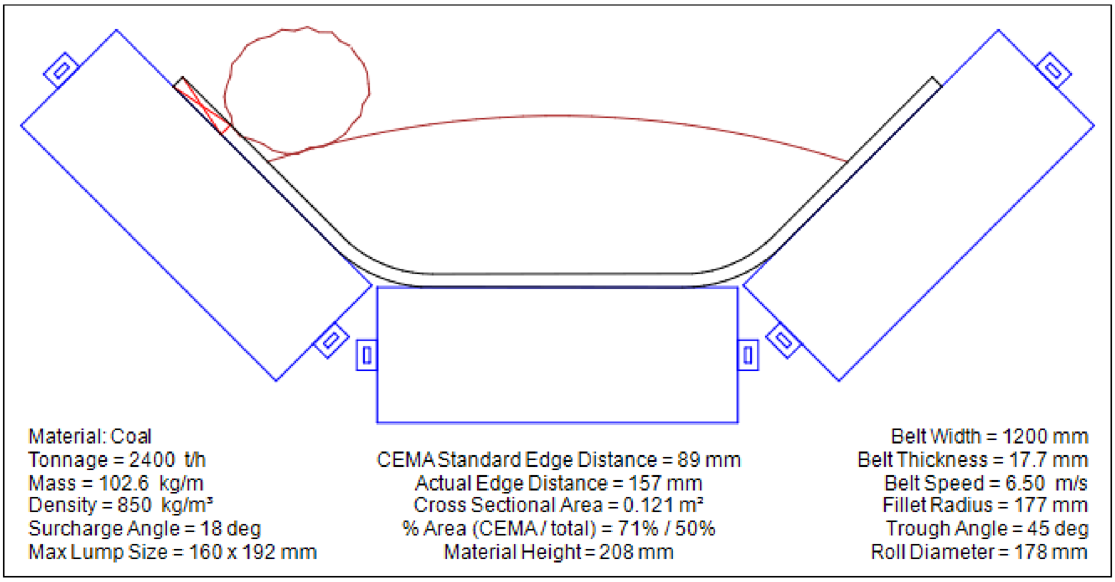

Figure 3. Cross sectional material loading profile at 6.5 m/s.

A triple drive head pulley arrangement with a 2-1-1 drive ratio was required. At the tail end of the conveyor another drive was also required. Each drive was rated as 1000 kW, totalling 5000 kW of installed power. The drive layout is shown in Figure 4.

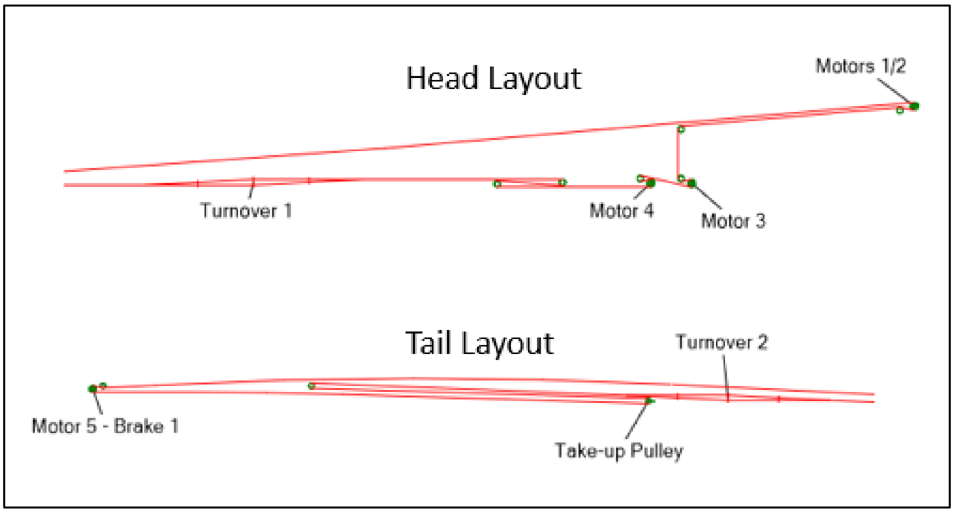

Figure 4. Head and tail drive layout with 5 x 1000 kW.

A proportional brake was required at the tail. The brake uses a velocity feedback control to stop the belt in 60 seconds under any loading condition. Figure 5 show the tail drive pulley and proportional brake.

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Figure 5. Tail drive and proportional braking system.

With over 42 km of total belting, the take-up system was another critical design component. A gravity take-up at the tail end of the conveyor was required (figure 6). However, neither flywheels nor a capstan brake was required.

This final configuration resulted in an extremely stable dynamic behaviour, even under the worst-case power failure and loading conditions. As such the long-term operation and reliability for the system is very high.

Figure 6. Gravity take-up tower at tail end.

2.2 HORIZONTAL CURVE DESIGN

The complex vertical and horizontal profile of this conveyor resulted in over 20 different load cases which needed of be analysed. These included loading (and unloading) the conveyor to various horizontal curve locations, loading the conveyor from the highest to the lowest elevation (and vice versa), and other partially loaded conditions. This was accomplished using the Sidewinder conveyor design software. Dynamic analysis during starting, stopping, and power failure condition were all simulated.

In the design stage each load condition is given a "design level" based on its potential for occurring. All load on/off conditions, as well as other everyday loadings are designated as design level 1 conditions. Conditions that can occur regularly such as a specific break in the loading which may result in a major incline or decline section loaded, are designated as design level 2 conditions. Finally, uncommon conditions such as multiple inclined or declined loadings are designated as design level 3 conditions.

After analysing all loading conditions and the full range of dynamic responses, the idler banking angles for each of the horizonal curves could be specified. Unfortunately, there is never a "single" ideal banking angle but instead a range of angles which result in the most stable belt positions. Using this range, and the potential for each design level, a final "optimal" banking angle can be determined. This angle results in the belt tracking within the idler frame under all steady state conditions. Side guide restraining rolls can be added as required. However, these are only for momentary and uncommon conditions. The gap between the guide rolls and the idler face, as well as the frequency of side guide rolls, is a function of the magnitude and the length of time various belt tensions occur.

The conveyor would pass near several small communities and as such noise was a design concern. A three-roll return idler set was selected along the entire conveyor route. The three-roll set significantly reduced the potential for belt flap and provides increased stability in the horizontal curved sections. HDPE rolls were used instead of typical steel rollers. This was to provide better performance, reduce vibration, and reduce the roller noise. In the end the system was significantly quieter than expected, particularly considering the 6.5 m/s speed.

Due to idler junction concerns, the idler spacing varied along the route. It initially started at 3 x 9 m (carry x return) for the first few kilometres, and then increased to 4 x 8 m. A spacing of 3 x 6 m was used in the horizontal curves. Figure 7 shows a typical idler and stringer arrangement.

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Figure 7. Idler and stringer arrangement along the conveyor.

2.3 POWER OPTIMISATION

For a conveyor of this length to even be possible, the design needed to be fully optimised. One essential component was the use of a low rolling resistance bottom belt cover compound. Various manufactures supplied rubber compounds for this system. AC-Tek internally tested these samples to verify those that meet the specific needs for this system. A range of testing was performed. This included rubber rebound testing, dynamic mechanical analyser (DMA) testing to obtain a complete rubber master curve for each compound, and other proprietary in-house testing performed by AC-Tek. Several manufactures were selected as potential suppliers. In the end, Dunlop Belting was awarded the contract and supplied the entire 42 km of belting.

2.4 FIELD MEASUREMENTS

After initial commissioning was completed, AC-Tek instrumented the conveyor to determine its initial operating parameters and provide baseline measurements for future reference. These measurements also ensured that the conveyor equipment and starting and stopping control algorithms were operating within the original design specifications. Conveyor measurement techniques and methodologies have been published by the authors in several other papers. [1,2,3,4]

Belt velocity encoders were installed at the head and tail, as well as the take-up pulley and counterweight position. Strain gauges were installed on each drive shaft. Strain gauging allows very accurate motor torque measurements to be recorded during both steady state and dynamic conditions. The proportional tail brake was also

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instrumented with strain gauges to record the braking torque during power failure conditions. Finally, measurements were made in critical horizontal curve locations in order to verify the belt's lateral displacements during loading and unloading.

The original final design report for the conveyor was submitted in January of 2014. The conveyor measurements occurred in September of 2016. Steady state and dynamic measurements were made over a range of conditions. The final measured demand power for the fully loaded conveyor was 7% lower than the original design calculations. This was an excellent result and showed the quality of the conveyor design, equipment, and installation.

Figure 8 shows the motor torques at the head of the conveyor and belt velocity when starting a partially loaded belt. The starting control is exceptionally smooth as would be expected with VFD's. The drives at the head are started and bring the conveyor to 5 % speed. However, due to the long length of the conveyor the belt must be uniformly pretensioned before full acceleration to avoid high momentary tensions. This pre-tensioning takes a significant amount of time before reaching the tail. As such the tail drive is not started until 45 second after the head drives. The control then maintains 5% speed for a period of time before being a smooth jerk free "S-Curve" acceleration ramp.

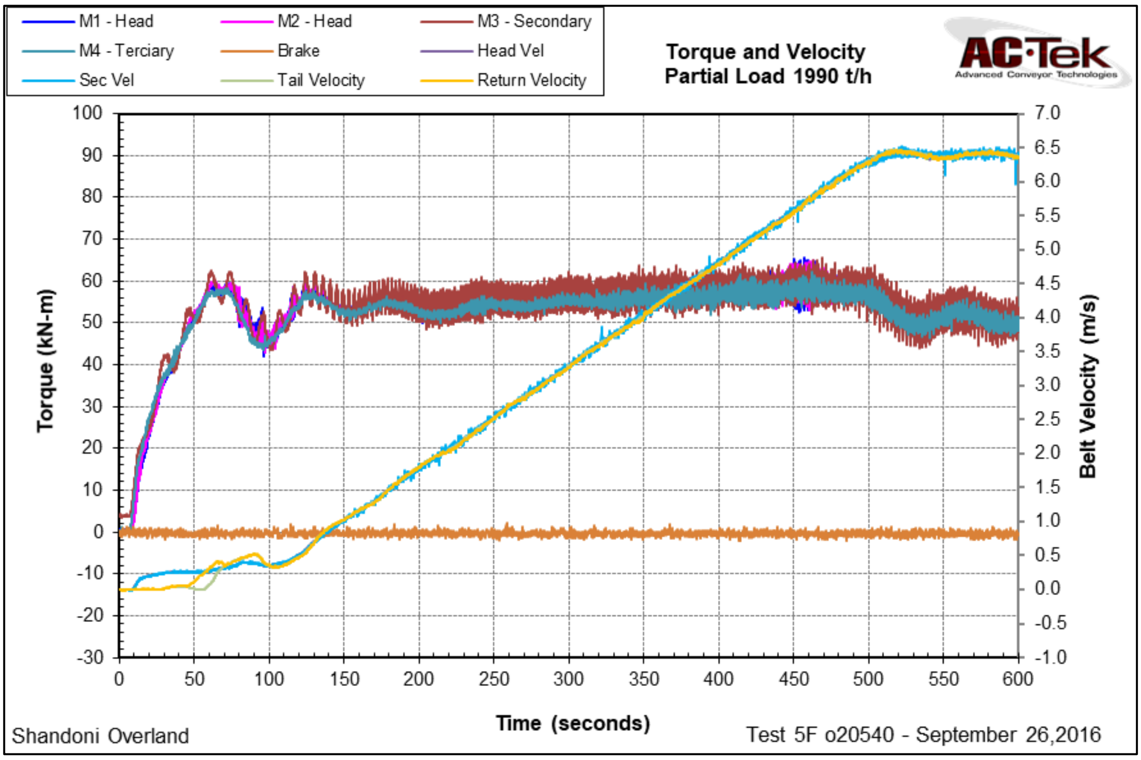

Figure 8. Head and tail belt speed and motor toque during starting.

Testing was performed on the empty belt, partial loading, and fully loaded conditions. Both operational and emergency stopping controls were tested to ensure the system was behaving as predicted. The resulting dynamic behaviour was indeed precisely as expected. Both the take-up travel and braking torque were functioning within the design requirements. [5,6]

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3.0 VALE S11D CONVEYOR CV-07

3.1 OVERVIEW

The VALE S11D project in northern Brazil is the world's largest Iron ore mine. The initial stage of the project was an astounding US$ 14.2 billion. This included a new mine, plant, railway system, port, and ship loading facility. Once operational the project expanded to US$ 19.5 billion. The system is now ramping up to full capacity and in the first three months of 2019 Vale exported 15.9 million metric tons of Iron Ore from the mine. Vale's target is to produce 90 million tons of iron ore in 2020.

Sandvik MGS & AC-Tek were awarded the S11D overland conveyor designs and supply contract in 2011. The S11D is a completely truckless mining operation. The ore is mined using blasting and shovel technique and is directly loaded onto a shiftable conveyor system (Figure 9). This then discharges into a small stockpile which functions as a 4-6 hour buffer for the overland system.

Figure 9. Truckless mining. Material is directly loaded onto the conveyor system.

3.2 OVERLAND SYSTEM

The stockpile then feeds material onto the overland conveyor system. The conveyors transport the material down the mountain to the plant and train loadout facility.

The 9.5 km overland system consists of four conveyors, each designed to transport a massive 19,200 t/h. Figure 10 shows an isometric view of the conveyor layout. The region is extremely mountainous and as such the path of the conveyor was governed by this terrain.

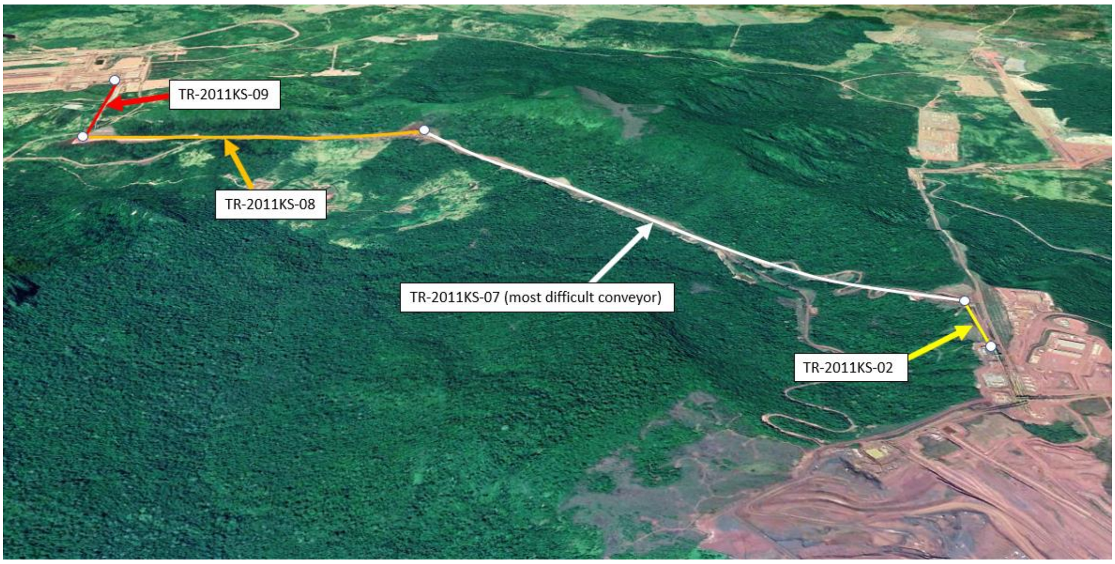

Figure 10. Isometric view of 9.5 km overland system consisting of four conveyors.

The most complex of the conveyors was TR-2011KS-07. This conveyor is just over 4.5 km in length. The first 1.5 km of the conveyor drops 215 m. To put that in perspective the material loading in just the initial declined section of the conveyor is roughly equal to the total gross weight of 50 fully loaded semi-trucks (assuming an average 30 metric tons per truck). The remaining 3 km traverses two moderate hills for an overall drop of another 15 m. An elevation view of the conveyor is shown in figure 11.

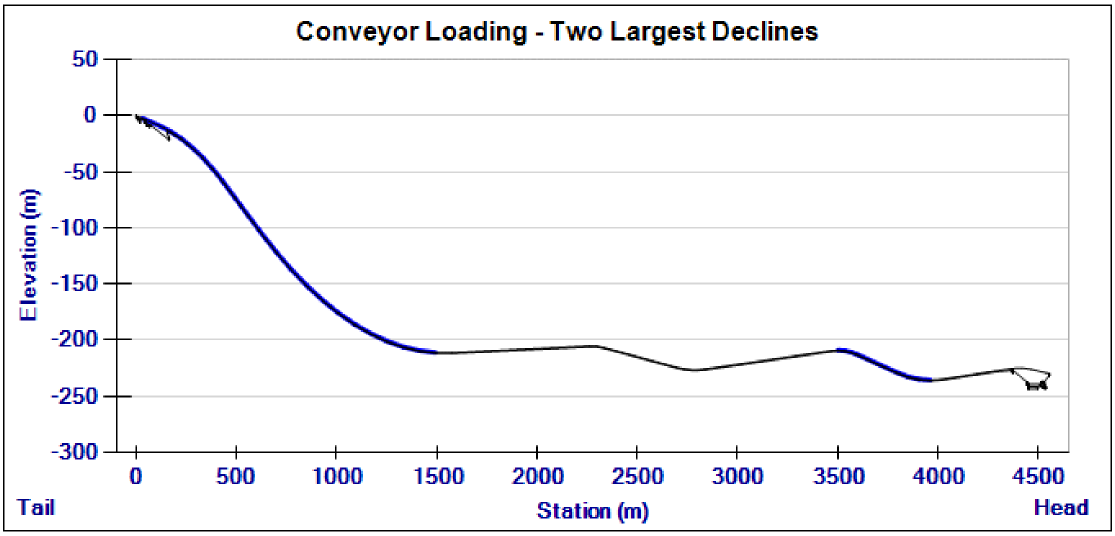

Figure 11. Elevation view of 4.5 km conveyor TR-2011KS-07.

One initial design considered splitting this conveyor in two. The first declined section would be one conveyor, and the longer undulating section would be the second conveyor. However, this configurate resulted in almost the same belt rating for the initial decline section as the undulating overland section. The first conveyor would require dual drives at the tail and dual head drives would be required on the second.

A single flight option still required dual head and tail drives, and it had almost the same belt rating. However, this option clearly eliminated the need for a transfer point and additional take-up system. A single flight option was more cost efficient and would require less maintenance.

The dynamic behaviour of this conveyor is very complex. Every time it is loaded, the decline section of the belt results in very high-power regeneration. During this load on condition the conveyor can regenerate almost 9,000 kW. However, when the conveyor is unloading and only the flat section of the conveyor is loaded the system can consume over 4,000 kW. Furthermore, if the decline section of the last hill was loaded (dark lines in figure 11), there could potentially be an additional drop of another 30 m of material. In this case the power could theoretically exceed 10,500 kW of regeneration.

All of these combinations resulted in a final installed power of 7 x 1500 kW motors, or a total of 10,500 kW. The final drive configuration uses 2500 mm drive pulley diameters with the head and tail layouts. Figures 12-14 show the head and tail layouts.

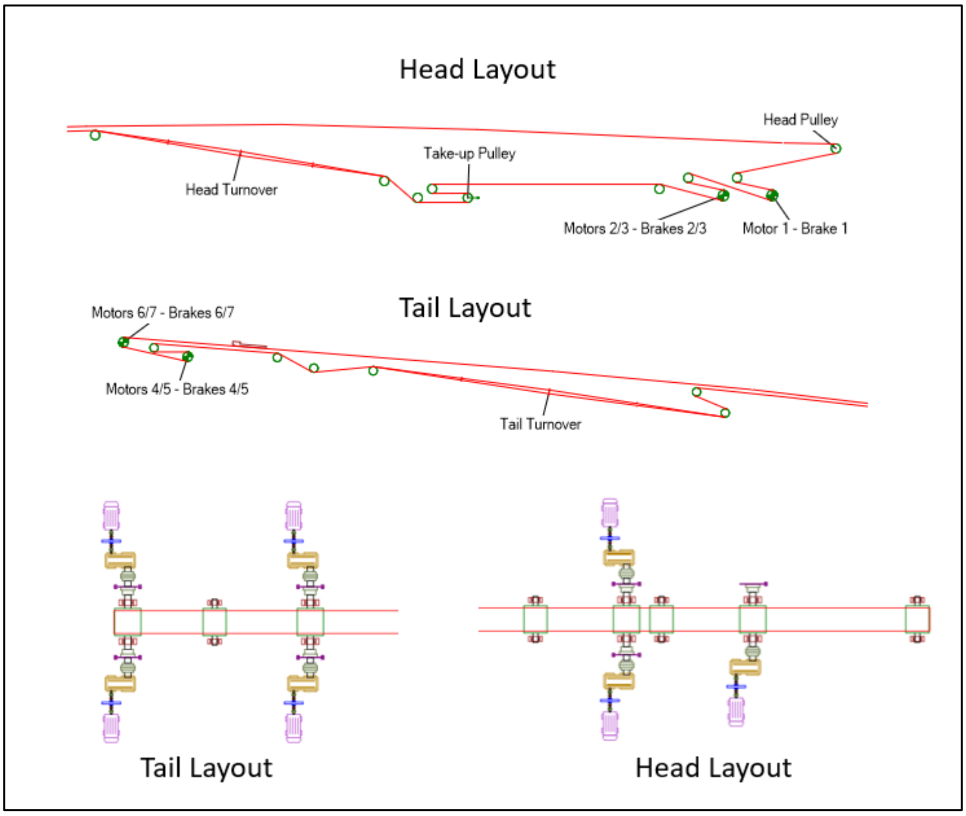

Figure 12. Head and tail drive layout for conveyor TR-2011KS-07.

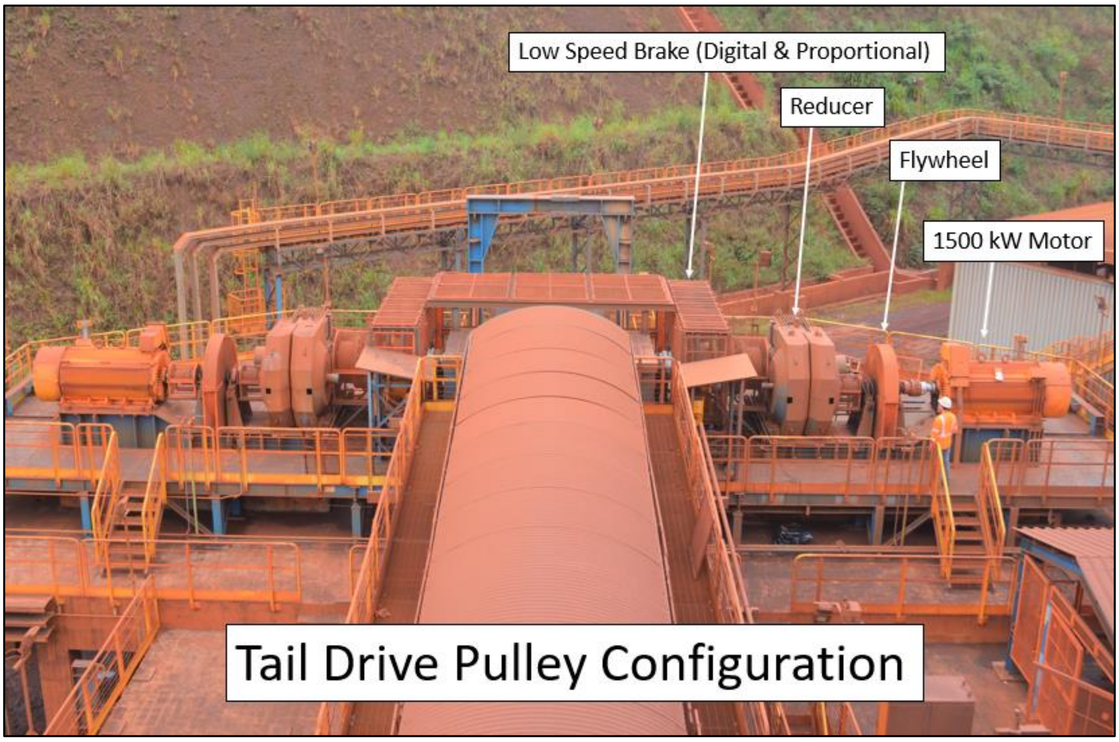

Figure 13. Tail drive layout for conveyor TR-2011KS-07.

Figure 14. Head drive layout for conveyor TR-2011KS-07.

3.3 BELTING / BRAKING

Braking requirements for this conveyor were enormous and almost double that of any other conveyor currently in operation. The total installed braking torque is an incredible 3,610,000 N-m. This braking torque is divided among all seven drive pulleys. It is further split between less expensive, but faster acting, constant torque brakes and slower, but more costly, proportionally controlled bakes. During operation the motor power is constantly monitored. Should a power failure occur, a set number of digital brakes are applied to provide the main braking force. The remaining proportional brakes are then applied to smoothly decelerate the conveyor. Johnson Brakes (Vancouver Canada) provided the brakes for this conveyor. Figure 15 shows one side of the seven low speed brakes. Each brake has two callipers (one on each side), and each calliper has two hydraulic cylinders. Figure 16 shows the massive size of a worn brake pad.

Figure 15. One of seven low speed brakes with both digital and proportional types.

Figure 16. Worn disk brake pad.

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To withstand these extreme loads and belt tensions, an ST-8000 N/mm belt rating was required. At the time of the design this was the largest belt rating in the world. The belt was provided by Goodyear and manufactured in the USA. The final belt selection was 2200 mm wide, with 19 x 10 mm covers, and operated at 5.0 m/s (figure 17).

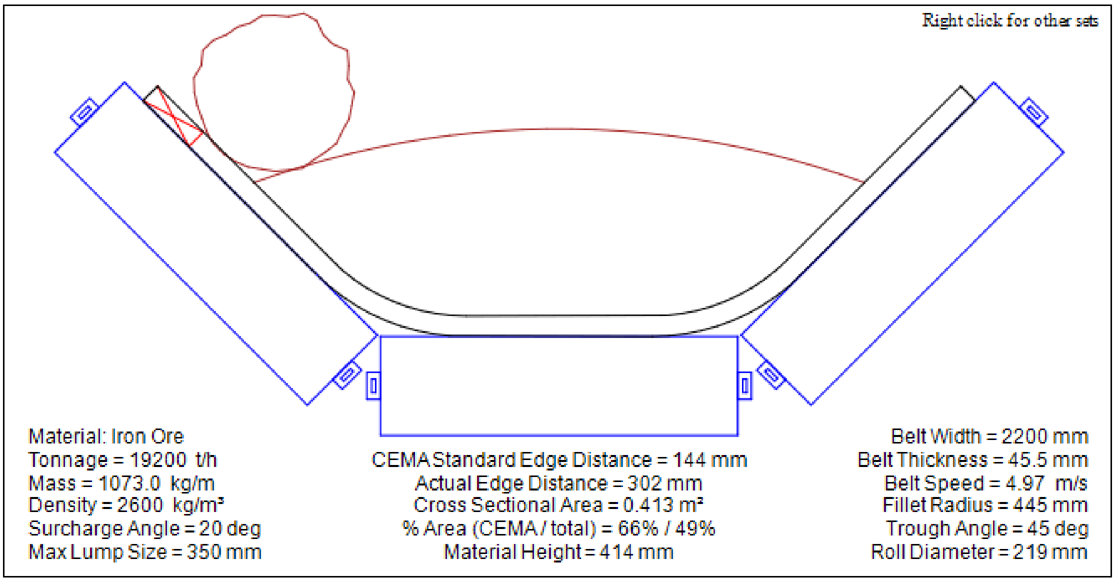

Figure 17. Cross sectional loading at 19,200 t/h and 5.0 m/s belt speed.

Due to the environmental conditions of Brazil's rainy season and the sticky nature of Iron ore, turnovers are a must on almost every conveyor at the mine. These conveyors were no exception. However, implementing turnovers on a 2200 mm wide, ST-8000 N/mm belt was yet another design challenge which had never before been accomplished. Determining the optimal turnover length is not trivial.[7,8,9] Too long of a belt turnover will result in excessive belt sag and buckling of the top outer cords in the middle. Too short a turnover length and the belt edges will be overstressed resulting in premature splice failure. The final 72 m turnover length balanced these two criteria and resulted in the world longest belt turnover. Figure 18 shows the installed belt turnover at the head station of the conveyor.

Figure 18. World's longest belt turnover of 72 m for an ST-8000 N/mm belt rating.

Although a gravity take-up was used on the other three conveyors, this was not practical on conveyor TR-2011KS-07 for several reasons, one of which was the very high belt tension required. As such an automatic winch was selected. The system, provided by ACE Winches in the UK, utilised two Hagglund hydraulic winches. It is capable of dynamically providing 2,600 kN of force on the take-up pulley (1,300 kN beltline tension). It is an actively controlled system that is continuously adjusting the take-up pulley as the load changes in order to maintain a constant belt tension. The cable has eight folds, using seven total sheaves each with a gigantic 2350 mm diameter.

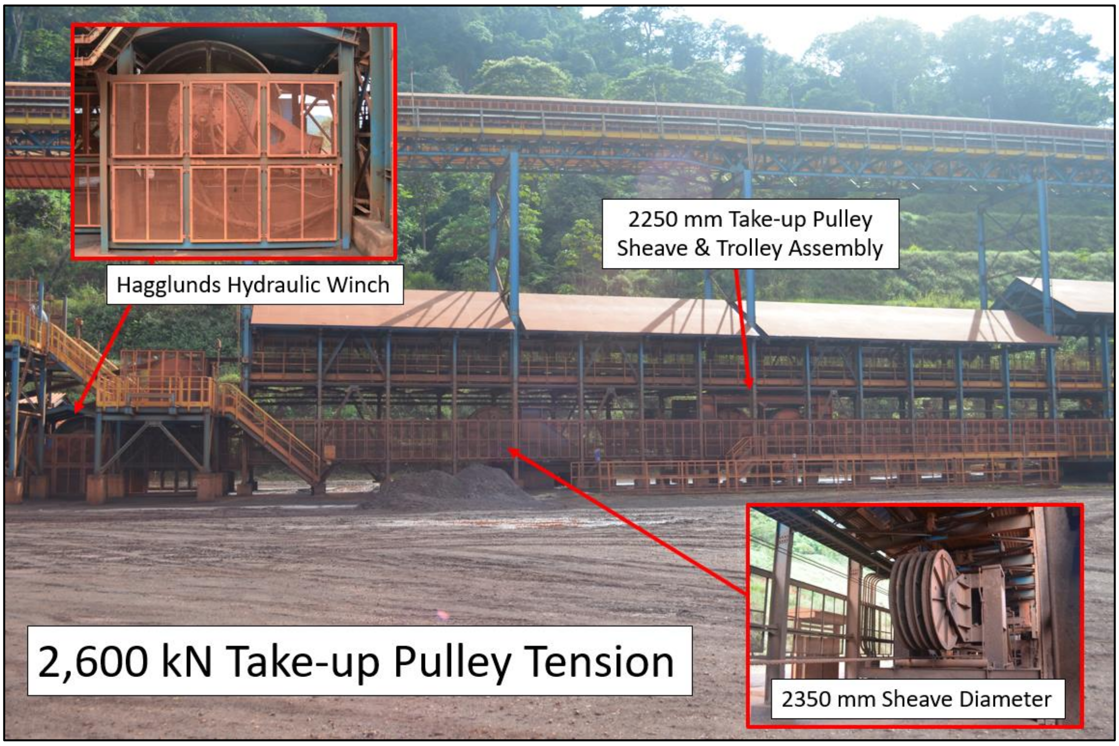

Figure 19. Automatic winch take-up supplying 2,600 kN of tension on the take-up.

3.4 INCREASING CAPACITY TO 21,000 T/H

In June of 2016 the conveyor system was successfully wet commissioned. At that time AC-Tek obtained a full set of field measurements on the conveyor. However, prior to these measurements the client contracted Sandvik & AC-Tek to provide them with a path to increase the tonnage from the initial 19,200 t/h to 21,000 t/h.

By obtaining a full set of measurements on the conveyor, AC-Tek came to the conclusion that the system capacity could be increased with only a change in speed. Furthermore, this speed increase would not require any mechanical modification. Normally either the reducers are replaced, or the drive pulley diameters are increased to accomplish this. On this system however, it was acceptable to simply run the motors over synchronous speed. As such the belt speed was increased to 5.4 m/s. This modification occurred in early 2018 and again the client requested that AC-Tek come and perform a complete set of field measurements of all four overland conveyors simultaneously.

These measurements required strain gauging all drive and brake pulleys. Additionally, on some motors, both the low speed and high-speed braking torque was obtained. This allowed differentiation of motor versus braking torque. In total 24 toque signals were simultaneously recorded over all four overland conveyors.

Figure 20 shows an example of a high-speed torque measurements. The strain gauge shaft is fitted with a battery powered transmitter that send the torque signal to a data recording device. Several other critical signals were also obtained including head and tail velocity, take-up position, take-up tension, various braking signals, and many PLC signals.

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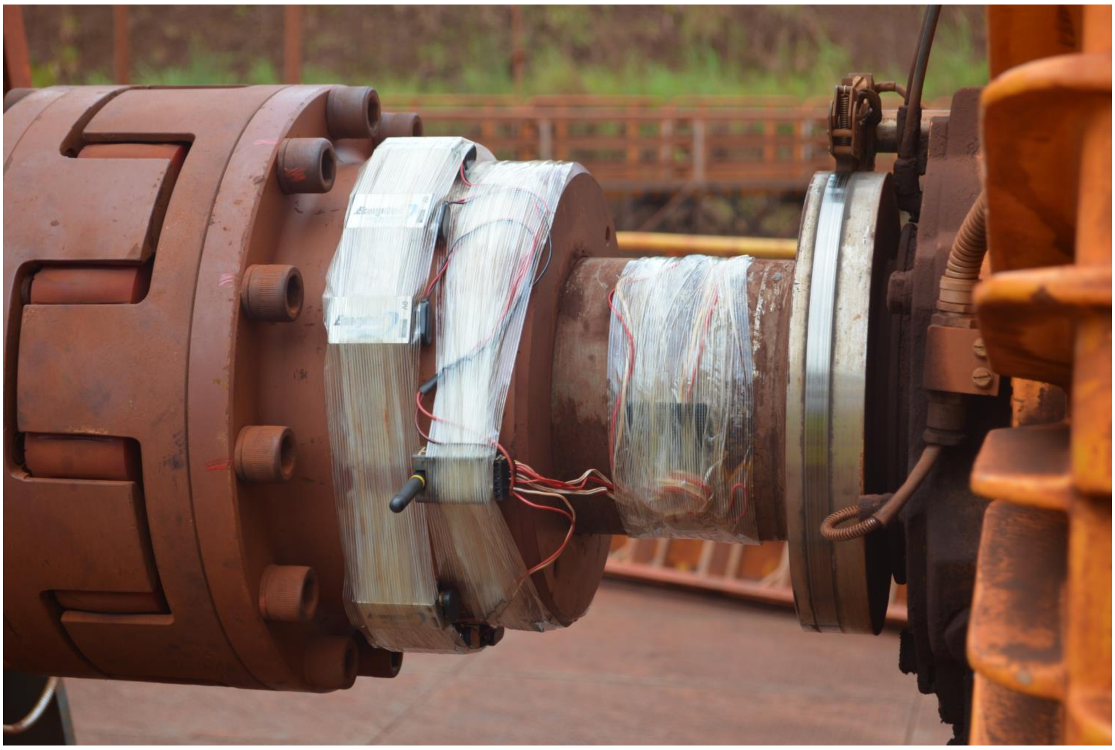

Figure 20. One of the 24 shaft torque measurements installed during commissioning.

Figure 21 shows the results of a partially loaded start on conveyor TR-2011KS-07. Initially the brakes are released as motor torque is ramp up to hold the belt. Once the brakes are fully released, the motors hold the speed at 5% to pretension the belt. This ensures that acceleration of the belt with be smooth without any high-tension waves. After the belt is pre-tensioned it is linearly accelerated with s-curve transitions at the beginning and end.

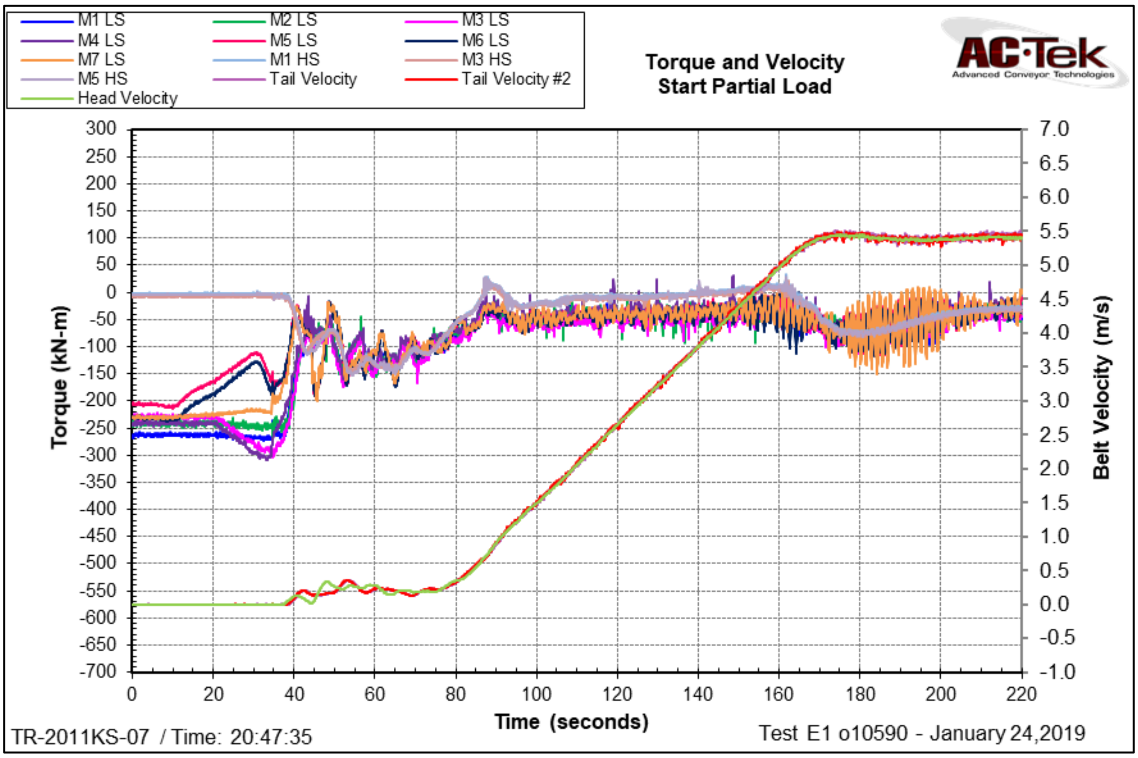

Figure 21. Belt speed and motor torque during a partially loaded start.

Figure 22 shows an emergency brake stop. Before the stop the motors are load sharing very well. The motors then turn off. This is seen when the torque on the high-speed shafts immediately goes to zero. The digital brakes then turn on followed by the proportional brakes. The braking system smoothly stops the belt in 35 seconds. The brakes at the tail apply approximately twice the steady state torque to decelerate the belt. The brakes at the head apply approximately 20% higher torque than steady state. The brakes at the head are smaller than the tail brakes to avoid excessively low tensions during stopping. The braking system operates within expected tolerances and does an excellent job of stopping the belt.

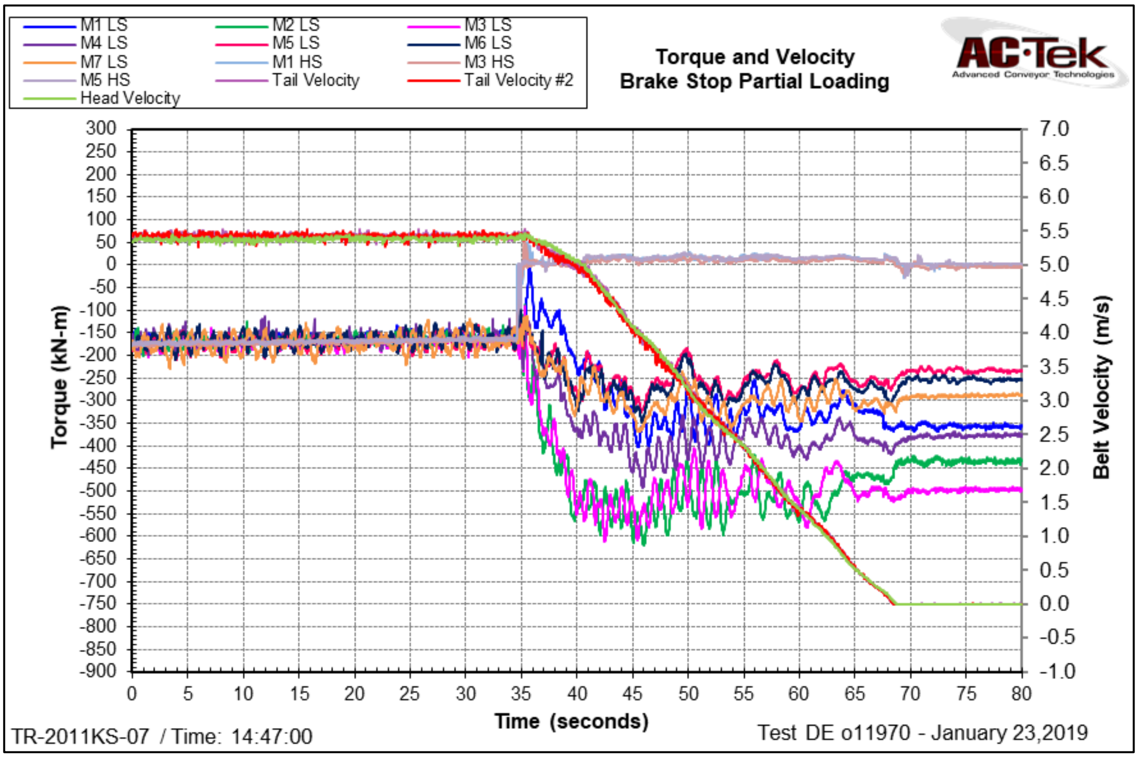

Figure 22. Belt speed and motor torque during an emergency brake stop.

Over 30 planned and controlled tests were performed. These included starting, operational stopping, various braking conditions, and PLC failure modes. Likewise, fully loaded, decline loading, incline loading, and various partial loading cases were all tested.

During this process several of the initial tests results were unacceptable. In each case the PLC programming or specific problem was corrected. The tests were redone to ensure the system was finally working as expected. In the end the system was fully operational and running consistently at the new increased capacity.

4.0 CONCULSION

This paper has described two of the world's leading-edge conveyors. Although very different, each system had its own unique design challenges. Overland conveyor technology has continued to evolve requiring engineers to provide better, and more optimal designs than in the past. Systems once considered unthinkable are now operating with exceptional performance and reliability.

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