El Brocal Overland Conveyor: Control System Re-design and Implementation

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SUMMARY

Demand from the Mining industry requires conveyors to efficiently and reliably transport bulk material long distances across difficult terrain at high throughputs. These conveyors are technically complex requiring multiple drive units and a robust control philosophy to control motor torque and tension distribution throughout the conveyor.

The successful implementation of the conveyor depends upon the seamless integration of the mechanical design and the control system to ensure safe and reliable performance under all operating conditions.

This case study examines the control system re-design and network modifications implemented by Conveyor Dynamics Inc. on the original El Brocal Overland Conveyor system to resolve problems associated with the conveyor drive torque control during starting, stopping and running conditions. These problems resulted in symptoms including erratic conveyor behavior, belt over tension, drive slip and inability to achieve nameplate capacity.

This paper details the problems found and provides an outline of the correct control philosophy that should be applied to multiple drive conveyors. The author then demonstrates the correct behavior of drives using this control philosophy by examining the results following successful implementation.

1 INTRODUCTION

In April of 2014 Sociedad Minera El Brocal SAA. (El Brocal), a subsidiary of Buenaventura, commissioned a new overland conveyor system at their Colquijirca mine located near Cerro de Pasco in Peru.

The overland conveyor system is a key infrastructure component of the El Brocal 18 kt/d expansion of operations, transporting primary crushed mineral ore from the Tajo Norte open cut mine to the concentrator plant located approximately 4.3 km distant, traversing across undulating terrain and skirting around a large water body.

Since commissioning, the overland conveyor system has been troubled by low availability due to several issues including chute blockages, belt damage and belt breakage which has prevented the expansion project from realizing the full design capacity.

Following continued low availability and ongoing severe belt damage El Brocal engaged Conveyor Dynamics Inc. (CDI) via their in country partner EGX Group SAC (EGX) in April 2016 to undertake an investigation and analysis of the problems in order to identify the root cause(s) and present solutions.

The major outcome of the investigation and analysis indicated that the root cause of the belt damage was the poor chute design and subsequent chute modifications. The direct coarse lump impact along with other contributing factors was causing severe belt damage and belt cord breakage. El Brocal had already commenced the process of re-designing the transfer stations to reduce the impact damage and therefore was justified in their decision by the results of the investigation.

However, during the investigation, examination of the PLC trend data also revealed that two of the conveyors which utilize multiple drive arrangements, were exhibiting symptoms of poor drive and load sharing control. This was identified as a contributing factor to the belt damage as individual drives on the same conveyor would at times be opposing each other up to their torque limit setting particularly during starting and stopping sequences resulting in excessive belt tensions. The poor drive and load sharing control also prevented the conveyors from starting and operating at nameplate design capacity due to drive overloading and belt slip traction issues. CDI's recommendation to El Brocal was to re-design the overland conveyor control system including the PLC logic and communications network to address these problems.

The focus of this article is the significant improvements achieved by CDI's re-design of the overland conveyor control system using the correct control philosophy which resulted in effective control the conveyor drives and load sharing during all operating conditions.

2 OVERLAND CONVEYOR SYSTEM

The El Brocal overland conveyor system comprises of a series of three (3) straight conveyor flights designated CV-002A, CV-002B and CV003 to transport primary crushed mineral ore at a design capacity of 1,500 t/hr to achieve 18 kt/d (Figure 1)

Figure 1 – El Brocal site plan.

Conveyor CV-002A is a relatively short downhill conveyor 861m in length with an overall fall of 47 m (Figure 2) utilizing a single 128 kW regenerative drive located at the tail pulley (Figure 3).

Figure 2 - Conveyor CV-002A vertical belt profile.

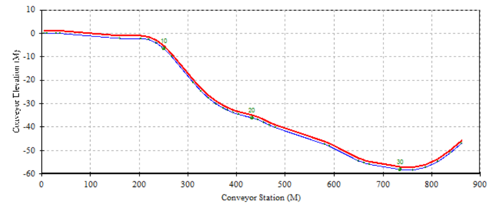
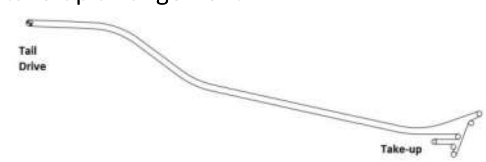


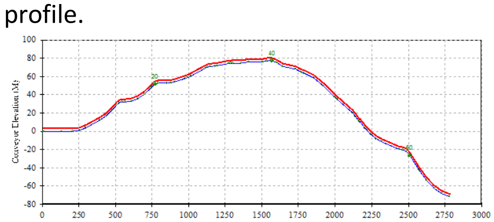
Figure 3 - Conveyor CV-002A drive and take-up arrangement.



Since this conveyor only has a single drive there was no load sharing control issues however the conveyor was included in the overall control system re-design in order to standardize with the other conveyor drive control philosophy on conveyors CV-002B and CV-003.

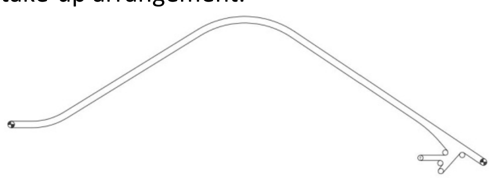
Conveyor CV-002B is a combined incline/decline conveyor 2,781 m in length with an overall fall of 72 m but with a 77 m maximum lift located approximately midway along the length (Figure 4).

Figure 4 - Conveyor CV-002B vertical belt profile.



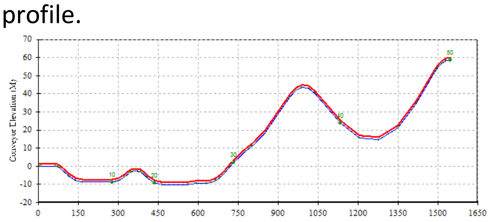
This type of conveyor profile presents a challenge to the conveyor designer as the conveyor can operate in both a regenerative condition when the decline section is loaded and conventional positive demand condition when the inclines are loaded. The drive arrangement selected by the original system designer was to install dual 168 kW drive motors at the tail pulley and dual 168 kW drive motors at the head pulley and locate the gravity take-up after the head drives (Figure 5).

Figure 5 - Conveyor CV-002B drive and take-up arrangement.



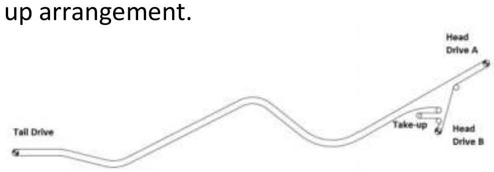
Lastly, Conveyor CV-003 is a predominantly an incline conveyor 1,547 m in length with an overall lift of 59 m (Figure 6). The belt profile on this conveyor features a large concave section prior to the head pulley where the conveyor passes through a gulley before inclining up to meet the upper level of the plant feed station. This concave is not significant enough to create a regenerative condition when only the decline sections are loaded hence conveyor CV-003 is effectively a true incline conveyor.

Figure 6 - Conveyor CV-003 vertical belt profile.



The original system designer selected a drive arrangement with a 206 kW drive motor at the tail pulley, a 206 kW drive motor at the head pulley (A) and a single 206 kW drive motor (B) adjacent to the gravity take-up located 210 m back at ground level remote from the head pulley (Figure 7).

Figure 7 - Conveyor CV-003 drive and take-up arrangement.



3 STARTTING AND STOPPING CONTROLS

The original drive starting and stopping control strategy for all conveyors utilized linear ramps generated internally within the drives with the start and stop signals broadcast by the plant PLC over the communications network to the head and tail switch rooms where drives are located respectively. Examination of the PLC code also indicated that the drives all operate in speed reference mode during the starting and stopping sequences.

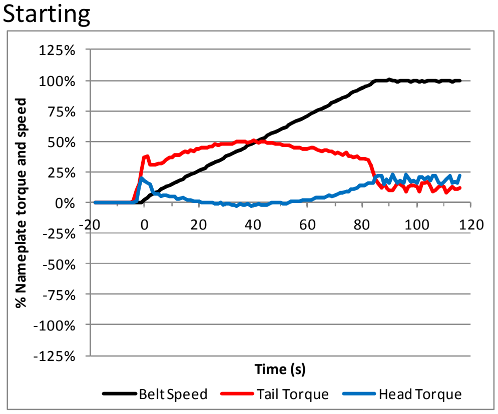
Whilst this strategy is generally not problematic, the use of the VFD internally generated ramps is limiting due to the preset ramp shapes available cannot be customized to suit the needs of complex overland conveyors. These conveyors often need an initial period of dwell to initially run the conveyor at a small fraction of full speed in order to redistribute unbalanced tension distributions within the belt from the previous stopping event before accelerating along the starting ramp. Additionally, the shape of the starting ramp affects the peak torque requirements of the drive as well as potentially causing torque and tension fluctuations if the rate of acceleration is discontinuous.

The use of the VFD internally generated ramps also places a high demand on communication network performance and latency as all drives must initiate their starting and stopping ramps simultaneously. Whilst this is generally not an issue for drives physically located within the same switch room, drives that are located several kilometers apart or even up tens of kilometers apart will suffer from communication delays unless the communications network is designed to accommodate (Cornet, 2002).

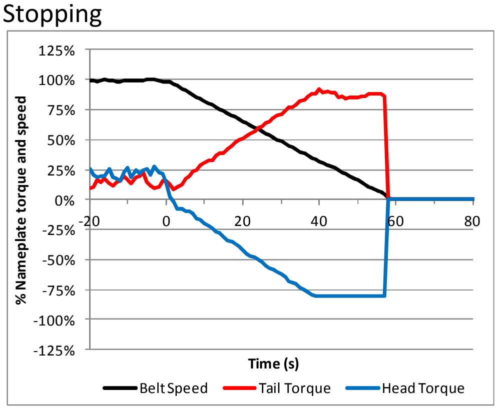
Analysis of the original PLC trend data obtained indicated that there were problems with the starting and stopping control strategy of the original conveyors. On conveyor CV-002B the drive torques between the head and tail were mirroring and opposing each other during starting and stopping which indicates that the drives are not following the same speed ramp or starting the speed ramp at the same time (Figure 8).

Figure 8 – CV-002B Starting and stopping motor torques – Original operation. Head and tail drives were mirroring and opposing each other.

Starting



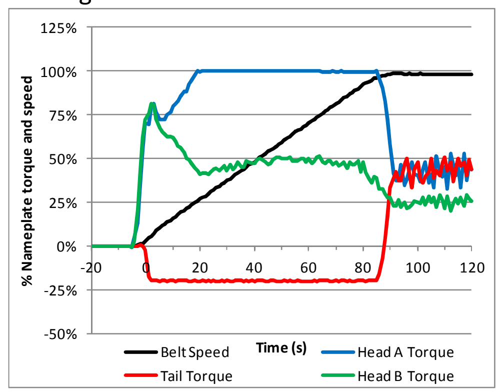
Stopping



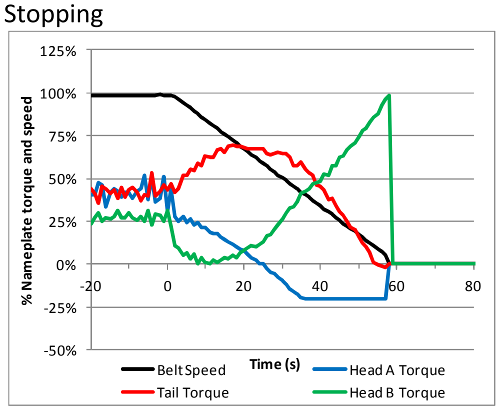
Similarly, on conveyor CV-003 the drive torques between the head and the tail drives were also mirroring and opposing each other (Figure 9) again showing the same problems.

Figure 9 – CV-003 Starting and stopping motor torques – Original operation. Head and tail drives were mirroring and opposing each other.

Starting



Stopping



Examination of the VFD ramp setting indicated the drives were utilizing the same speed ramp therefore the problem was attributed to the drives not starting the ramps at the same time. This effectively results in some of the drives trying to accelerate the conveyor whilst the other drives are trying to decelerate the conveyor in order to follow the defined speed ramp set point. During a long start or stop ramp sequence this ultimately results in drive torques increasing or decreasing progressively to their torque limits can also results in excessive belt tensions as drives oppose each other rather than working in unison.

The poor drive synchronization during starting and stopping was therefore due to poor communication network performance where the start and stop signals from the plant PLC were being delayed and received by the head and tail drives at different times. An investigation of the original communication network revealed that all drives, remote I/O and peer systems were operating on the same LAN network connection. The original communication system was simulated using Rockwell Integrated Architecture Builder (IAB) which revealed that the network was operating at 184% utilization and therefore was confirmed as the root cause of the drive synchronization issues.

CDI proposed to change the original communication network configuration by redistributing the network load over two separate peer and remote I/O networks as well as replacing the original CompactLogix to a higher capacity ControlLogix PLC in order to eliminate the drive synchronization issues.

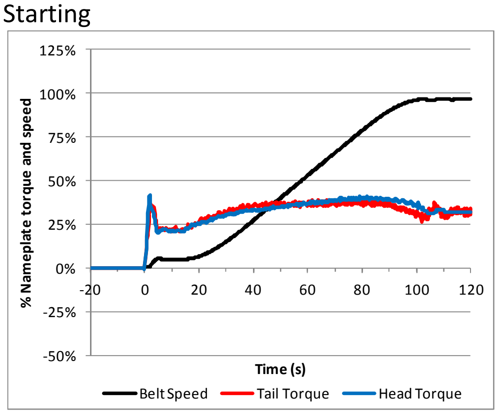
In addition, all speed ramp generation was removed from the drives in order to be performed within the plant PLC. Whilst the reconfiguration of the communication network should effectively mitigate the synchronization issues alone, there is an additional advantage of performing all speed ramp generation within the plant PLC. By continuously broadcasting the speed set point update for all of the drives during the speed ramp sequence, any effect of a delay in a drives receiving the speed reference is minimized as the drives will receive the correct value typically within the following seconds and recover.

On conveyor CV-002B, the change to performing the ramp generation with the PLC also enabled CDI to modify the starting ramp to incorporate a 20 second dwell period at 5% speed followed by a 80 second S curve ramp with an extended linear section. As noted previously, the dwell period effectively redistributes unbalanced tension distributions within the belt from the prior stopping event prior to accelerating along the starting ramp. An extended linear section of the S curve was also utilized in order to reduce peak starting tensions in the conveyor as it was identified that the conveyor has marginal installed power available for starting under adverse inclines loaded conditions at the full design capacity.

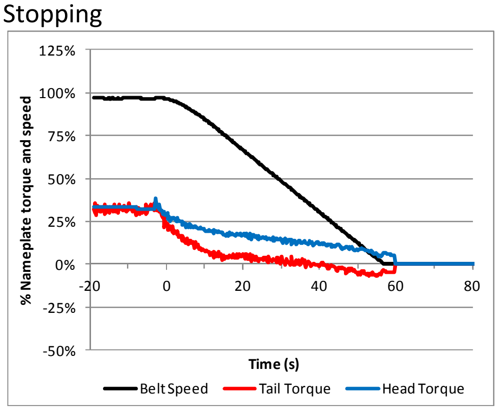
Following the onsite modifications and re-commissioning of the communication system and conveyor control system the PLC trend data was analyzed to verify the starting and stopping issues have been resolved. Conveyor CV-002B now starts and stops smoothly with the head a tail drives working together in unison (Figure 10).

Figure 10 – CV-002B Starting and stopping motor torques – After control changes. Head and tail drives are working in unison with similar torque levels.

Starting



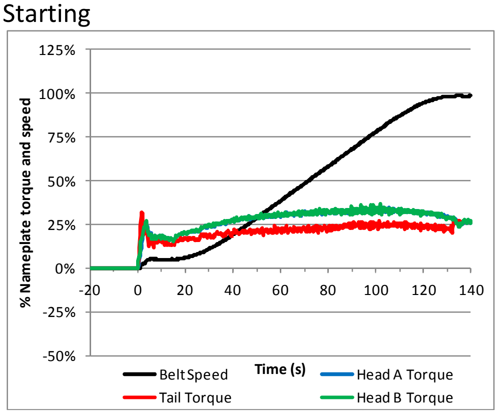
Stopping



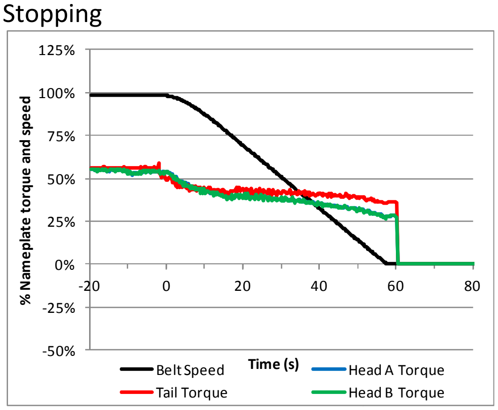
Similarly, conveyor CV-003 also now demonstrates smooth starting and stopping behavior with all drives working together in unison following the CDI modifications (Figure 11).

Figure 11 – CV-003 Starting and stopping motor torques – After control changes. Head and tail drives are working in unison with similar torque levels.

Starting



Stopping



It must be noted that the torque levels between drives on the same conveyor are not always equal during the starting and stopping sequences. Torque load sharing between drives during starting and stopping is also not the correct philosophy because each drive on the conveyor must develop the individual torque level required in order to achieve the required speed set point throughout the starting and stopping sequence. To achieve this, all drives must operate in a speed reference mode such that they are able to generate the required torque level, within limits, to achieve the speed set point issued by the PLC generated ramp function. Load sharing between drives on conveyors must only be implemented when the conveyor is running at steady speed.

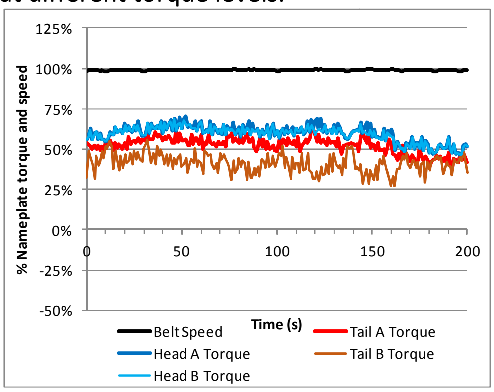
4 DRIVE LOAD SHARING CONTROLS

The original drive load sharing control strategy on conveyors CV-002B and CV-003 assigned one drive as the master and all other drives as torque slaves. Examination of the original PLC code indicated that the torque output level of the master was being read by the PLC and issued to the conveyor slaves as a torque set point in a torque reference mode once the conveyor was running at speed.

This load sharing strategy is problematic in general, due to the dynamic response of the conveyor as individual drive torque output levels change and the response time for this change to be felt by the other drives. As an example, the conveyor total torque demand level increases as the conveyor is progressively loaded, the master drive will absorb more torque in order to maintain the conveyor speed. The increase in master torque level is sent by the PLC as a new torque set point to the other conveyor drives which then also increase their torque output. However, the total torque output is now too high and is sensed by the master drive some many seconds later (depending upon conveyor length) and therefore decreases its torque and the cycle repeats (Cornet, 2002). This oscillation in torque levels can become unstable and practically cannot be eliminated through the use of control based proportional, integral and derivative control loop methods due to the complex and elastic nature of the mechanical conveyor system.

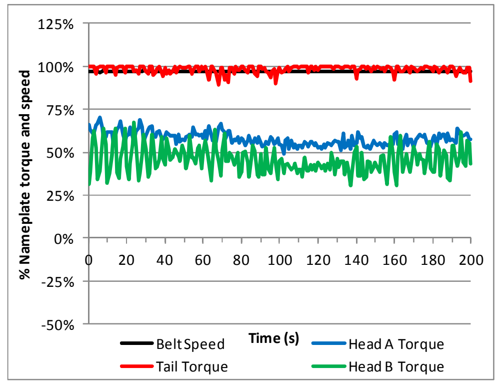
Analysis of the original PLC trend data obtained indicated that there were problems with the drive load sharing control strategy of the original conveyors once the conveyors were operating at speed. On conveyor CV-002B the drive torque levels between the head and tail drives were not only unbalanced but the drive torques between drives A and B on the same pulley shaft were also unbalanced and oscillating (Figure 12).

Figure 12 - CV-002B Running motor torques – Original operation. All head and tail drives were unbalanced and operating at different torque levels.



Similarly, on conveyor CV-003 the drive torque levels between the head and tail drives were unbalanced with the tail drive operating continuously at 100% nameplate (torque limit setting) as well as the two head drives operating at different torque levels with large torque oscillations present (Figure 13).

Figure 13 - CV-003 Running motor torques – Original operation. All head and tail drives were unbalanced and operating at different torque levels and showing oscillation.



In order to correctly load share between multiple drives on the same conveyor CDI proposed to implement both hardware configuration changes to the drives located within the same switch room as well as implement a PLC based torque load sharing strategy between drives located at the head and tail end of the conveyors except during starting and stopping (Cornet, 2002).

The control of conveyors utilizing multiple drives located at the head and tail end is generally the domain of long overland conveyors such as Impumelelo (Thompson, 2016), Curragh (Steven, 2008) and Zisco (Nordell, 1997) however the conveyor profiles and drive arrangement by the original conveyor design requires similar control philosophies even for relatively short and low tonnage conveyors.

Drive load sharing control philosophies between individual drives on the same conveyor can be divided into three methods namely:

1) drives with motors mounted on the same pulley shaft. These drives should always be configured in a direct drive torque master-slave relationship such that both drives act in unison as they operate on the same pulley shaft at exactly the same speed (Cornet, 2002).

2) drives located in the same switch room but with motors mounted on separate pulleys. These drives should always be configured also in a direct drive torque

master-slave relationship such that both drives act in unison but with a slower torque response rate on the slave to avoid localized oscillation as they operate on different pulley shafts connected by a short elastic section of belt (Cornet, 2002).

3) drives located in separate switch rooms along the conveyor which cannot operate in a direct torque master-slave relationship both due to physical communication distances but primarily due to the fact they operate on different pulley shafts connected by a long elastic section of belt. These drives should be configured to operate in a PLC based torque load sharing scheme (Cornet, 2002).

Regardless of the method, there must only be one drive that is operating in speed reference mode as the true master drive of the conveyor that defines the operating speed of the whole conveyor belt. All other drives must be operating as torque slaves using one or a mixture of the above methods (Cornet, 2002).

In order to achieve correct load sharing between drives on conveyor CV-002B, CDI proposed to assign Tail Drive A as the true master drive of the conveyor with Tail Drive B configured as a direct torque slave to drive A (Method 1). The tail drives were assigned as the true master drives due to the regenerative potential of the conveyor in which the tail drives must rapidly respond to the regenerative condition and control conveyor over speed. The Head drives were therefore configured to operate under a PLC based torque load sharing control scheme with the tail drives (Method 3). There are several schemes for PLC based torque load sharing control which is dependent upon the functionality required by the conveyor mechanical design. Since the original mechanical design of the conveyor was not being changed, CDI proposed to use an equal load sharing scheme with dead band control to prevent instability and oscillations between the head and tail drives.

If this was a new conveyor installation with the same design requirements, CDI would typically size the drives such that the tail drives would absorb all of the regenerative demand torque and the head drives consume all of the positive demand torque for the declines and inclines loaded conditions respectively. This can be shown to greatly simply the conveyor control philosophy. In the case of the original conveyor CV-002B, all motor installed capacity is required together working in unison for both the inclines and declines loaded operating conditions.

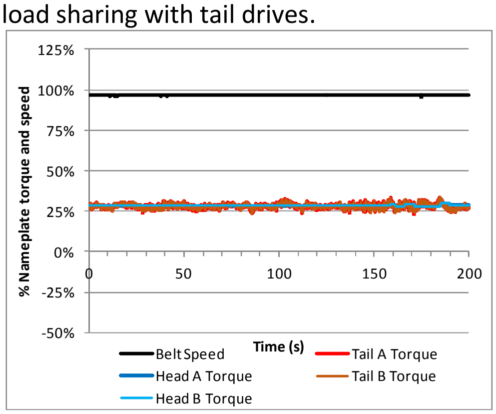
For correct load sharing of conveyor CV-003, CDI proposed to assign the Head drive B as the true master drive of the conveyor with Head Drive A configured as a direct torque slave to drive B (Method 2). Drive B was selected as the master as it has a fixed low side tension governed by the gravity take-up and sets the low side tension of the Head drive B which effectively manages belt slip. The tail drive was configured to operate under a PLC based load sharing control scheme with the Head drives (Method 3). Similarly to CV-0002B, since the original mechanical design of the conveyor was not being changed, CDI proposed to use an equal load sharing scheme for the Tail drive with dead band control to prevent instability and oscillations between the head and tail drives.

If this was a new conveyor installation, CDI would typically not utilize a tail drive on this conveyor as it is a relatively short incline conveyor. The original conveyor CV-003 requires all motor installed capacity under the inclines loaded condition and therefore the tail drive could not simply be removed unless larger or additional drives were installed at the head end of the conveyor.

CDI modeled the original conveyors and simulated the proposed load sharing control philosophy for conveyor CV-002B and CV-003 using our proprietary BeltFlex dynamic conveyor analysis code in order to verify the correct operation under all operating conditions (Nordell and Ciozda, 1984).

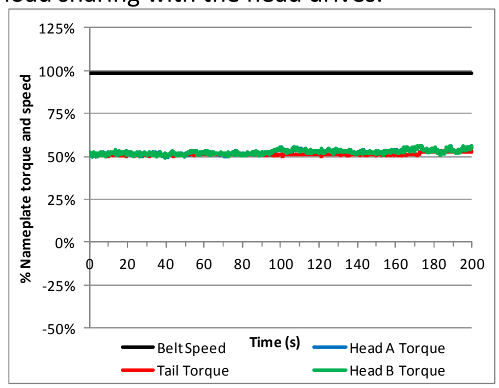
Following the onsite modifications and re-commissioning of the drive configuration and conveyor control system the PLC trend data was analyzed to verify the drive torque load sharing issues have been resolved. Conveyor CV-002B now operates with all drives equally sharing the conveyor load with the Tail drives torque fluctuating in response to the speed reference operation and the head drives gently modulating under the PLC based dead band load sharing torque control (Figure 14)

Figure 14 - CV-002B Running motor torques – After control changes. All drives operating at similar torque levels with head drives operating in PLC based dead band load sharing with tail drives.



Similarly, conveyor CV-003 now also demonstrates good load sharing behavior with all drives equally sharing the conveyor load with the Head drives torque fluctuating in response to the speed reference mode and the Tail drive gently modulating under the PLC based dead band load sharing torque control (
Figure 15).

Figure 15 - CV-003 Running motor torques – After control changes. All drives operating at similar torque levels with the tail drive operating in PLC based dead band load sharing with the head drives.



5 CONCLUSIONS

Whilst the El Brocal overland conveyors are relatively short and low capacity in comparison to larger overland conveyor systems, the vertical profiles of the conveyors and the arrangement and sizing of drives by the original system designer resulted in a relatively complex conveyor drive system which demanded the correct drive control philosophy be utilized.

As originally designed and commissioned, the El Brocal overland conveyor system exhibited poor multiple drive control with drives not working in unison and actually opposing each other during starting and stopping sequences. In essence, the control system was not able to control the conveyor in accordance with the original mechanical design requirements.

Following the PLC control system changes and modifications to the communication network the El Brocal Overland conveyor system was able to operate safely, reliably and efficiently at the rated design capacity utilizing the correct implementation of multiple drive control philosophy to suit the original mechanical design.

6 REFERENCES

Cornet, J., 2002,
"Head and tail controls in long overland conveyors", *Bulk Materials Handling by Conveyor Belt*, Vol. IV, pp. 55-67.

Nordell, L.K., 1997
"Zisco installs world's longest troughed belt – 15.6 km horizontally curved overland conveyor", *Proceedings of Beltcon 9*, Johannesburg, South Africa.

Nordell, L.K. and Ciozda, Z. P., 1984
"Transient belt stresses during starting and stopping: elastic response simulated by finite element methods", *Bulk Solids Handling, Vol 4, No. 1, pp 93-98.*

Steven, R.B., 2008
"Belting the world's longest single flight conventional overland belt conveyor", *Bulk Solids Handling, Vol 28, No. 3, pp 172-181.*

Thompson, M. and Jennings A., 2016
"Impumelelo coal mine is home to the world's longest belt conveyor", *Mining Engineering, Oct 2016, pp 14-35.*