Case Study

Design and Control Philosophy of the 4.7 km NMDC Downhill Conveyor in Kumaraswamy, India

Edited by on 31. Aug. 2020

This paper describes the mechanical design and control philosophy of one of the most complex conveyor installations in the world, if not the most complexed. NMDC contracted ELECON/CKIT Conveyor Engineers (collaboration) to design the horizontal curve downhill conveyor. ELECON was awarded the contract in 2010, against strong competition.

Fig. 1: Downhill conveyor from head to tail.

The conveyor transports 2000 tph of iron ore material from the crushing plant at Kumaraswamy mine to an existing screening plant, at Donimalai, which is approximately 5.20 km away. The 4.7 km downhill conveyor was commissioned in September 2017 for the NMDC Steel plant in Kumaraswamy, India (Fig. 1).

Introduction

NMDC Limited, a premier iron ore producer in the world and export house for high grade iron ore lumps and fines, is presently engaged in mining activities at Donimalai, located in the district of Bellary, Karnataka State, India.

NMDC proposed, in 2010, to develop the Kumaraswamy iron ore mines for a ROM (run of mine) capacity of 7 million tonnes per annum to produce calibrated lump sizes of -30 mm to +10 mm and fines of -10 mm. With this in mind a crushing plant was built which was 5.2 km from the existing screening plant. It was proposed to convey the material down the mountain from the new crushing plant to the screening plant via a series of conveyors which included a downhill conveyor Fig. 2).

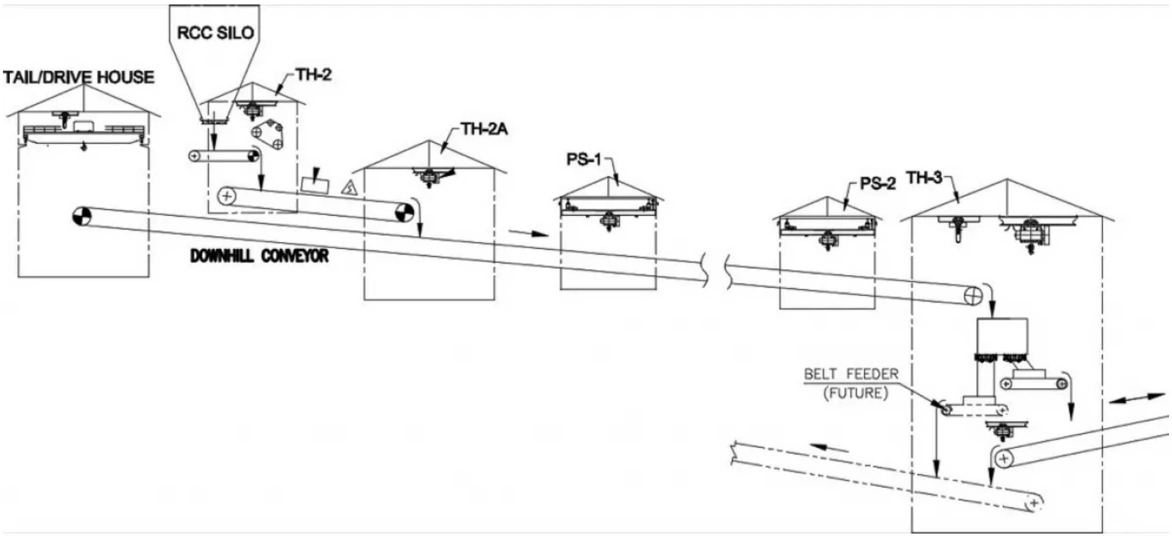

Fig. 2: Flowsheet showing downhill conveyor

Design Methodology

The selection of the mechanical equipment and arrangement/location of critical equipment tested every bit of experience in the bulk materials handling industry. The conveyor is complex in every sense, being a regenerative conveyor, compromising of four horizontal curves, six vertical curves, belt turnover devices, horizontal gravity take-up with a counterweight tower and a brake control system. It is also equipped with a traveling trolley to do maintenance 60 m above ground. See Fig. 3 below showing the conveyor profile.

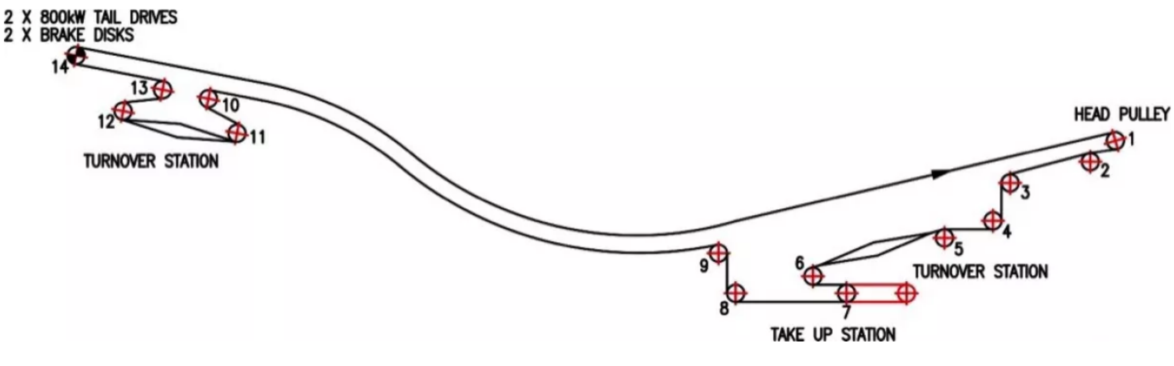

Fig. 3: Conveyor profile

Design Features of the Downhill Conveyor

High Speed Conveying

The long downhill belt conveyor operates at a speed of 6.0 m/s and is transporting 2000 tph of iron ore. This results in cost effective transfer of ore as per the following criteria:

- using a narrow belt width of 1050 mm, instead of 1400 mm,
- four numbers of horizontal curves thus eliminating transfer towers,
- increased idler spacing, and
- compact triangular gantry design.

Due to the selection of high speed for the conveyor, a small belt will allow for the design of a lightweight technological structure, small curve radius and low material load on belt.

With reducing material load, the idler spacing can increase therefore minimizing the idler quantities and also idler-roll material cost. See Fig. 4 showing the material loading profile of the conveyor.

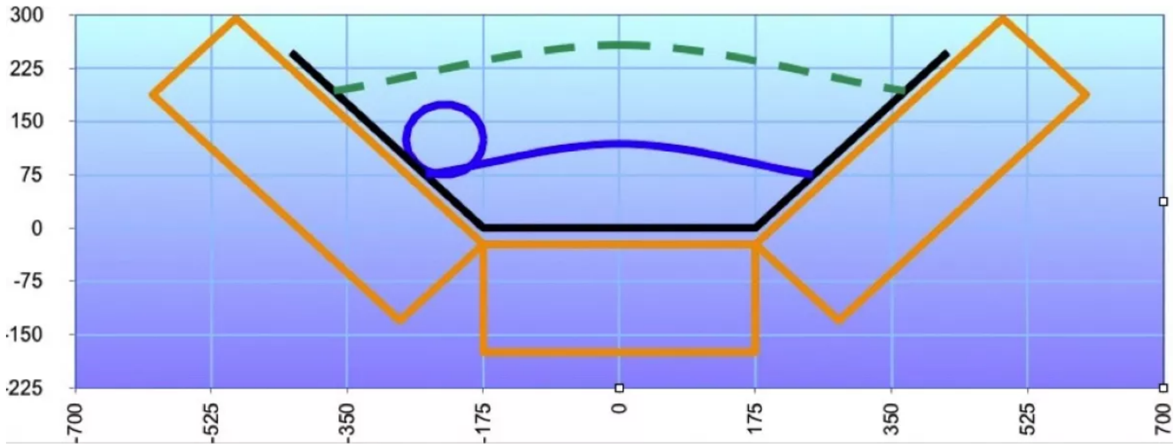

Fig. 4: Material loading profile

Horizontal Curves

This conveyor consists of four horizontal curves which eliminates the need for three additional transfer towers with structure, chutes, drives and electrical infrastructure, dust extraction and maintenance/operating personnel. This increases the reliability of the total belt system.

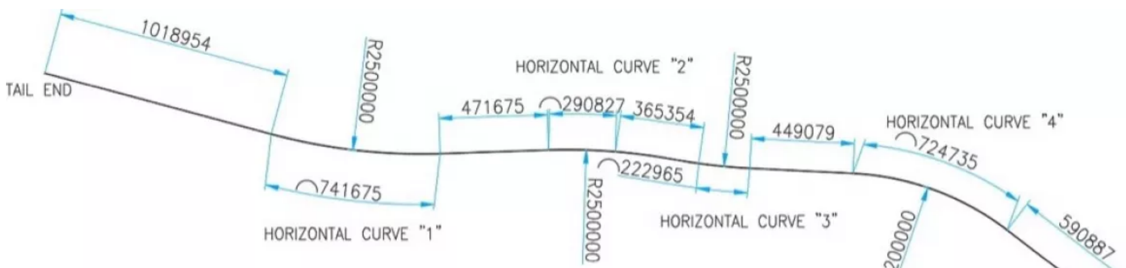

Fig. 5: Plan view on conveyor profile

Fig. 6: Photo showing one of the horizontal curves

To prevent the runoff of the belt from the idlers, the idler stations in the horizontal curves have to be placed under a banking angle. A narrow centre idler and larger wing rolls is used to help control the belt drift in the horizontal curves. Reduced idlers spacing in the horizontal curves was also introduced to help with belt drift.

Dynamic curve analysis was carried out to predict the belt drift in the horizontal sections.

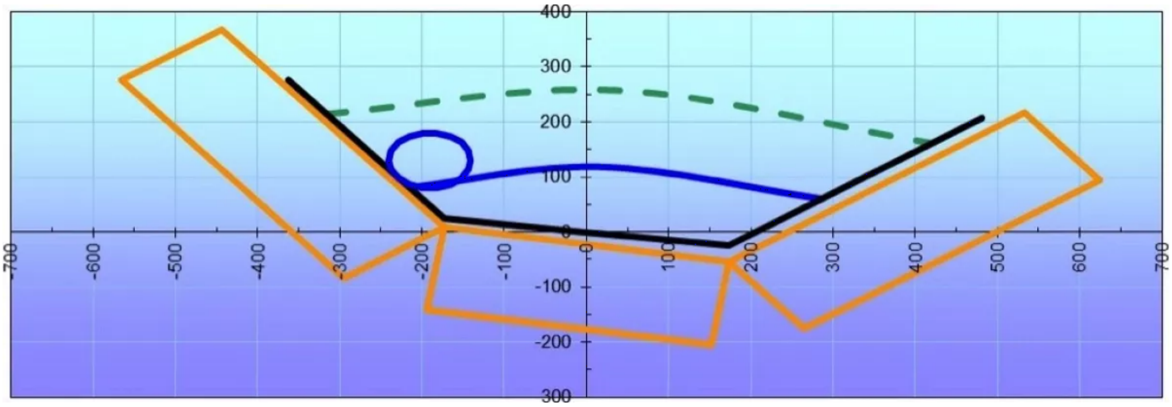

Fig. 7: Idler banking angle analysis showing belt drift

Triangular Pipe Gantries with Traveling Maintenance Trolley

The overland gantries are fabricated from standard tube sections on to which conveyor technological structures are mounted. A significant feature of this gantry design is the absence of access walkways throughout length of the conveyor. Removing the need for access walkways reduced the overall structural cost. The tubular structure allows greater spans when compared to conventional gantry profile steel design.

Fig. 8: Conveyor crossing gorge at 50m elevation

The trolley automatically provides full access to the conveyor belt for inspection and maintenance purposes. The trolley is used by the maintenance personnel to travel the full extent of the conveyor belt on a daily basis. So, for long belt Conveyors, this is the best way to eliminate walkway access throughout the length of the conveyor.

3-Roll Return Side Idlers

To help control belt displacement in the horizontal curves, a three-roll idler set is used on the return side of the conveyor. The use of a 3-roll return set increases the longitudinal stiffness of the belt. Therefore, the belt flap and resonance are typically much better than a conventional two-roll VEE return system.

Furthermore, the idlers can be pitched farther apart, which offsets the cost of additional rolls. For example, on a conveyor with a 4 m VEE return spacing, a three-roll set could use 8 m. Therefore a smaller number of rolls and idler frames are required.

Belt Turn Over on Return side

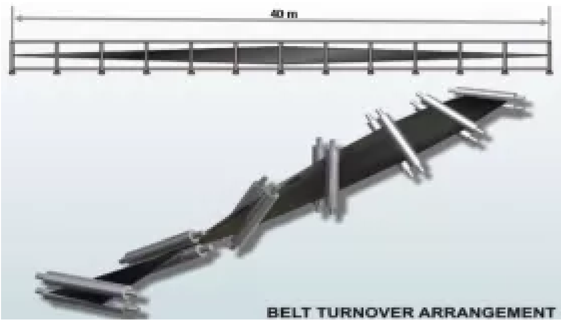

Fig. 10: Typical Belt Turnover Arrangement

40 m belt turnovers were installed on the system with five supporting zones. All different belt tensions, twisting and bending stresses and sag were looked at during the design of the turnover.

The turnovers served three distinct purposes:

- To keep the return side idlers clean. This increases the idler life and reduces maintenance and belt vibration.
- To prevent excessive fatiguing of the belt at the idler junction joint due the three roll return idlers.
- To Reduce the belt tensions. The belting incorporated a low rolling resistance rubber compound on the bottom belt cover, which would be in contact with both the carry and return side idlers.

Belt

The conveyor has a 1050 mm × ST 3150 N/mm belt. The cover thicknesses are 9.0 × 5.0 mm (top × bottom). The belt weight and the belt elasticity used in the analyses are 30.4 / 39.1 kg/m and 227,200 kN/m respectively. See Table 1 below for maximum belt tensions and safety factors.

Table 1: Maximum belt tensions and safety factors.

	Maximum tension steady-state operation [kN]	Maximum tension start up operation [kN]	Maximum tension shut down operation [kN]	Safety factor non-steady-state operation [-]
Empty	304	365	477	6.93
F load	403	452	626	5.28
I load	304	388	465	7.11
D load	512	556	661	5.00

The belt is also equipped with rip detection system with sensors embedded in the top cover of the belt at 100 meter intervals.

Take Up Tension and Dynamics

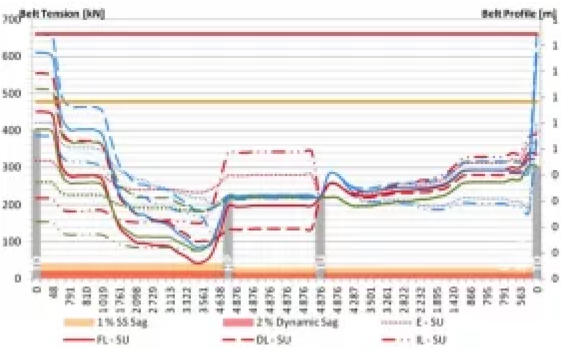

Fig. 11: Tension Distribution during Various stationary and non stationary cases

The take up was an important part of the design with regards to the location and arrangement. The take-up was sized by considering all load cases with regards to belt sag, belt drift and the operational conditions. Dynamic analysis was also carried out to predict the displacement of the take up and counterweight at all possible conditions. Fig. 11 shows the tension distribution.

The total take up travel with double reeve system concluded to a travel of 20 m. The take-up travel due to tension variation during operation, the so-called tension travel, is summarized in Table 2 and Fig. 12 shows the take up travel during start up.

Table 2: Total take-up travel.

Dynamic tension travel (max-min)	7.30 m
Thermal growth	2.00 m

Belt age creep	2.90 m
2 splices	3.20 m
Clearance	4.60 m
Total travel	20.0 m

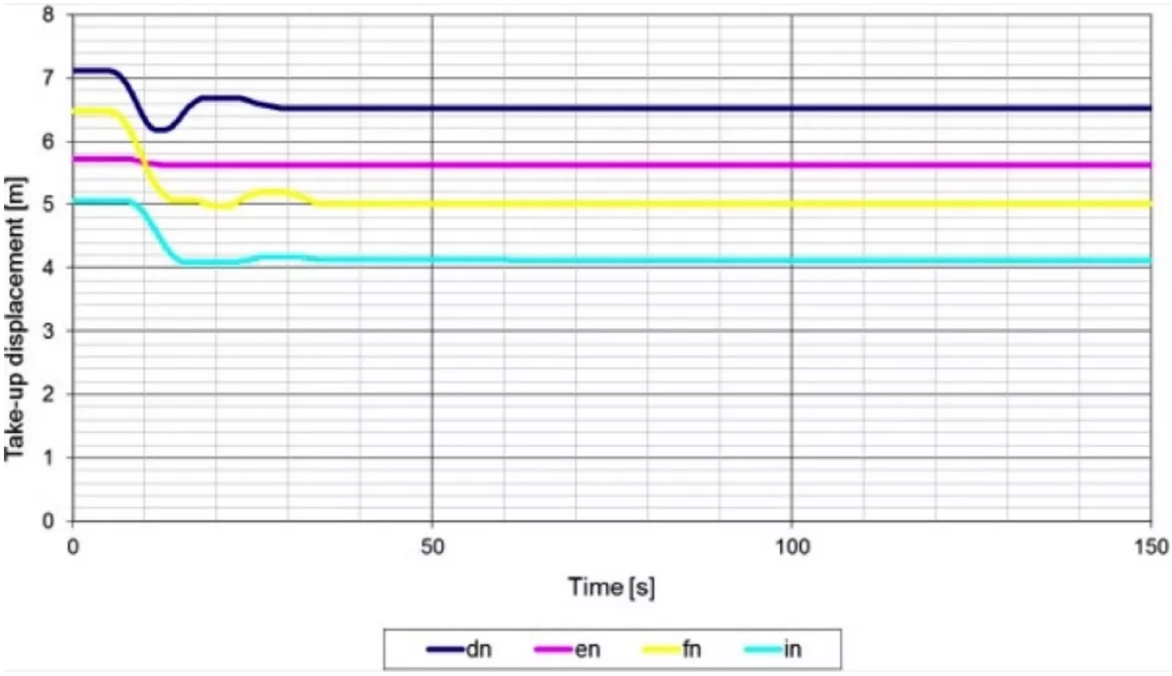

Fig. 12: Take up travel with Operational Start

Pulley Design

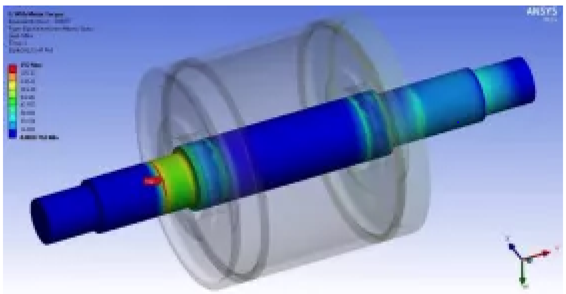

Fig. 13: Finite Element Analysis

The pulleys in the conveyor system are arranged as shown in Fig. 3 (turnovers at the head and tail pulley are not shown). The pulley design considers major tensions only for the selection of shaft, bearing, end disk and shell design. All pulleys were analyzed using Finite Element Analysis software as shown in Fig. 13.

A 1400 mm diameter tail pulley was selected with 410 mm hub diameter shaft which stepped down to 340 mm diameter on the bearings. The head pulley is equipped with a 1250 mm shell diameter with 380 mm on the hub and 340 mm diameter on the bearings.

Drive Analysis and Torque arm Arrangement

The conveyor has two 800 kW tail drives that is controlled by VSD/VFD; the total drive power available is 1600 kW. The drives can start and stop the conveyor under all load conditions. See the summary in Table 3 of the required power consumption at different loading capacities.

Table 3: Power consumption summary.

Load condition	1 E	2 FL	3 FL	4 FL	5 FL	6 FL
Capacity [%]	0	20	50	70	100	120
Capacity [tph]	0	400	1000	1400	2000	2400
Idler friction [kN]	4.4	5.0	5.9	6.5	7.4	8.0
Belt flex [kN]	33.4	33.4	33.4	33.4	33.4	33.4
Material flex [kN]	0.0	10.6	26.5	37.1	53.1	63.7
Pulley resist. [kN]	0.0	-39.5	-98.7	-138.2	-197.4	-236.9
Material lift [kN]	1.5	1.5	1.5	1.5	1.5	1.5
Misc. [kN]	3.2	3.2	3.2	3.2	3.2	3.2
Effective tension [kN]	42.6	14.3	-28.1	-56.4	-98.8	-127.1
Abs. power [kW]	255.4	85.7	-168.7	-338.4	-592.9	-762.5

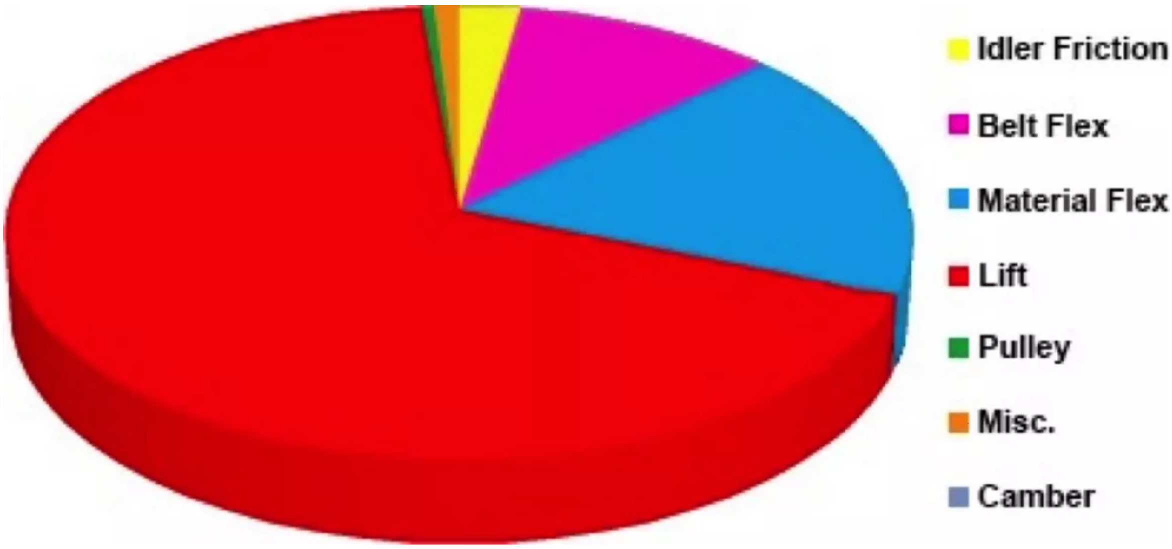

Fig. 14: Pie-power analysis at fully loaded steady state condition

Table 4 provides a summary of the power demand during the different steady state conditions at different belt loadings.

Table 4: Power demand.

Power demand	Empty	Fully loaded	Declines loaded	Inclines loaded
Absorbed or regen. [kW]	255	-593	-1245	900
Demand power [kW]	314	730	1533	1108
Demand / installed [%]	20	46	96	69

The torque arm location of the drive base plates was also analysed considering all different belt tensions and all possible operating conditions. This data provided the best possible location for the torque arm location.

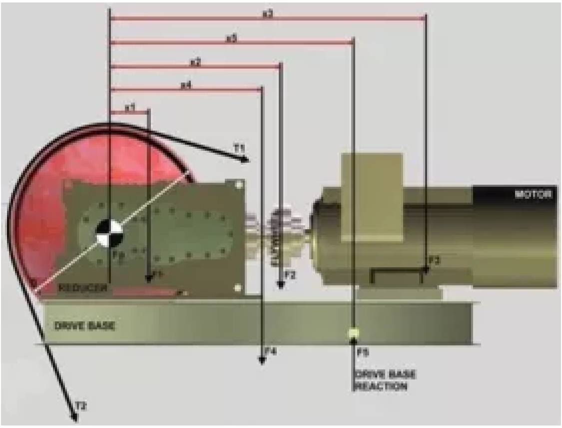

Fig. 15: Diagrammatical analysis procedure of torque arm position

Low Speed Brake System

This belt conveyor, being a downhill system, is equipped with a tail brake system mounted on the tail drive pulley. There are two brake disks selected each with a double caliper having a brake rating of 65.2 kNm each. (Total torque available is between 130.4 kNm and 260.8 kNm).

Two control systems are provided, one being digital and the other proportional to stop the conveyor. On each disk, one caliper acts in a digital manner, on/off with quick response and one caliper acts proportionally with a control pressure to regulate the additional braking torque.

The sequence of brake operation can be varied according to the load conditions on the conveyor belt.

When the conveyor is in a regenerative condition the “digital, on/off” brake calipers are applied first, utilising the fast response of this circuit to limit the accelerations that are been generated. Subsequently the proportional circuit would be brought into play to control the deceleration of the conveyor belt.

Fig. 16: Tail drive pulley with brake a caliper arrangement

If the drive torque is positive, or only slightly regenerative, the proportional brake calipers would be first applied to control the deceleration of the conveyor. The required brake torque is determined by the value of the torque from the VFD. If the torque is too high for proportional braking for a controlled stop in the right time, then the digital calipers would be applied at the same time that the proportional calipers reduce to a low (10%) value to be able to resume the complete control functionality.

Braking Modes and Philosophy

Motors and VFD

- It should be emphasized that the normal mode of stopping the conveyor is a controlled stop using the drive’s VFD control system, which is the inverse of the starting S-curve. After the conveyor come to a complete standstill the brakes are applied.

Normal Braking

- In the event of power failure, the conveyor is brought to rest as i) above using the VFD drives which is equipped with a battery back-up system
- In the event of VFD failure the braking system stops the conveyor according to a pre-programmed speed “S-curve”. Should the power fail at the same time the UPS back-up would maintain the control functionality for the braking system during the stop.

Emergency Braking

- If the brake controller and VFD drives are unavailable, together with a power failure and the UPS fails, the digital brake calipers apply immediately and the proportional brake calipers then apply slowly until full load based on the torque measured before the unit failures.

Over Speed Braking

- When the over speeding occurs and the VFD`s are unavailable, the brake controller initiates a controlled stop using the digital and proportional braking systems.

See Table 5 for different braking scenarios.

Table 1: Caption sits here.

	Mode of braking	Total braking torque 4 calipers [kNm]		Braking time [s]	Total braking torque 2 calipers [kNm]		Braking time [s]
		Digital	Proportional		Digital	Proportional	
Empty	With motors & VFD	–	–	–	–	–	–
	Normal braking (in case of power failure, with UPS active)	0	7.3	60	0	7,3	60
	Emergency stop (in case of power failure & brake controller PLC failure)	130.4	130.4	7.66	65.2	65.2	13.9
	25% Over speeding of conveyor	130.4	130.4	9.2	65.2	65.2	16.1

	Mode of braking	Total braking torque 4 calipers [kNm]		Braking time[s]	Total braking torque 2 calipers [kNm]		Braking time [s]
		Digital	Proportional		Digital	Proportional	
Fully loaded	With notors & VFD	–	–	–	–	–	–
	Normal brakes (in case of power failure, with UPS active)	130.4	8,6	60	65.2	65.2	68.4
	Emergency stop (in case of power failure & brake controller PLC failure	130.4	130.4	21.86	65.2	65.2	68.4
	25% Over speeding of conveyor	130.4	130.4	26.23	65.2	65.2	82.11
Downhill loaded	With motors & VFD	–	–	–	–	–	–
	Normal braking (in case of power failure, with UPS active)	130.4	74.9	60	65.2	65.2	2 Calipers cannot brake the conveyor, however it will eventually stop on the up hill section.

	Mode of braking	Total braking torque 4 calipers [kNm]		Braking time[s]	Total braking torque 2 calipers [kNm]		Braking time [s]
		Digital	Proportional		Digital	Proportional	
Emergency stop (in case of power failure & brake controller PLC failure)	130.4	130.4	27.3	65.2	65.2		
25% Over speeding of conveyor	130.4	130.4	38.9	65.2	65.2		

Start Up Procedure

The conveyor start is controlled by variable speed drives. The inverter start-cycle will be 150 seconds long, however 10% belt speed will be maintained for 20 seconds prior to introducing the start up control loop. It is first necessary to start releasing the brake under a controlled condition prior to engaging the drive motors.

The tail drive pulley is brought to full speed in 150 seconds following a delayed “S” shaped velocity curve as can be seen in Fig. 17. The delay is to make sure the head and tail pulleys speeds are synchronized.

As the conveyor is regenerative under some load conditions and therefore the brakes will apply at zero speed.

Conclusion

This paper shows all the design parameters on how to go about designing complex high-speed regenerative conveyors consisting of horizontal curves.

With this conveyor pushing every design component to the next level, one can say design codes and standards only provide a guideline, they don’t dictate the design.