SANDWICH BELT HIGH ANGLE CONVEYORS -BROAD HORIZONS 2023

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FOREWORD

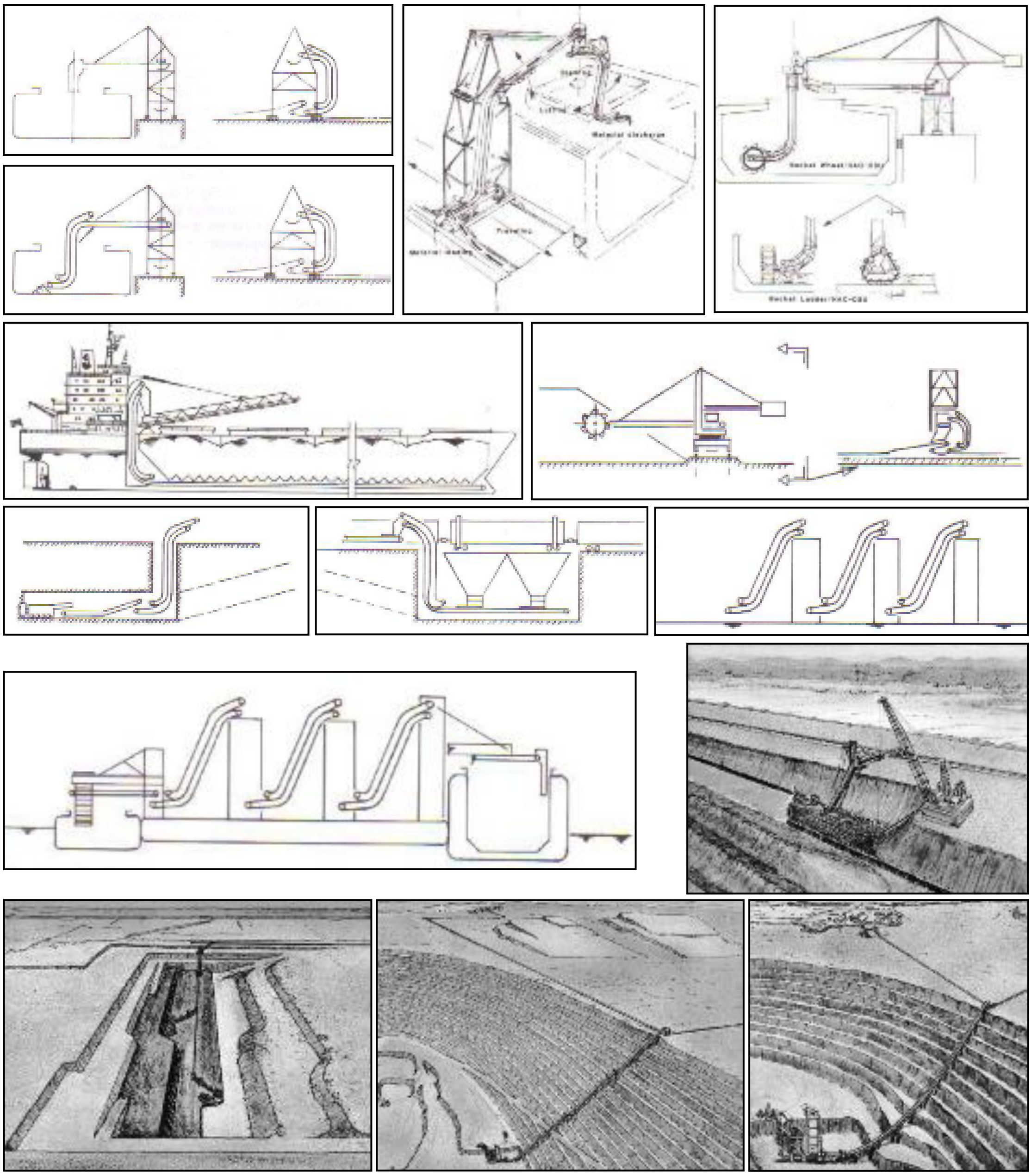

Figure 1 – 1981 vision of the "Broad Horizons" for Sandwich Belt high angle conveyors; continuous ship loading/unloading, materials handling yards, construction /tunnelling, transfer terminals, land based, floating, mining, etc.

The theoretical basis for the Dos Santos Sandwich Belt high angle conveyor systems was developed by J.A. Dos Santos between 1979 and 1981 as part of a study titled "High Angle Conveyor Study" which was funded by the USA Bureau of Mines, Department of the Interior. The sketches of Figure 1 pointed out the many possible applications in materials handling, at transfer yards, ports, land based and floating terminals, mines, construction, tunnelling, etc. This occurred at the end of 1981 and beginning of 1982, a troubled time in world politics and economics. “Broad Horizons” , a paper discussing the options presented in figure 1, was first published in 1987 and it established the means to periodically track the Sandwich conveyor development progress. It was subsequently published in 1992 and most recently in 1999. In this current writing, 24 years later, progress is revisited. Whereas many of the predictions have been realized, some have not. On the other hand, some significant developments have been made that were not foreseen in the original presentation.

ABSTRACT

The present writing is a compilation of developments in Sandwich Belt high angle conveying made over the years, most since 2002 and the most significant in the last several years. Some of these developments apply more generally, including to conventional open troughed belt conveyors.

This starts with significant developments:

1. A hybrid Snake and GPS system that exploits the best of both techniques to address the roadway span and vertical lift requirements of elevating shredded tyres to fuel the boiler at a Texas, USA cement plant.
2. The patented Adder Snake system, that can envelop the approaching conventional conveyor with its bulk load, elevate it continuously at any high angle then release it to continue its low angle conveying path.
3. The patented TBM Trailing Sandwich Belt high angle conveyor that can continuously clear the muck from a TBM (Tunnel Boring Machine) when operating along any high angle.

None of these three innovations are specifically foreseen.

Next are presented the basics of conveyor geometry including:

- Establishing what is a proper conveyor belt line and its implications,
    - Especially with various troughing geometries including troughing idlers with long middle rolls.
- The mechanics of transitions from troughed to flat (at pulleys).
- Developing the material carrying capacities for the various troughing geometries.

Finally, are some optimisations that have resulted from real world experiences including:

- Better containment of the bulk through the inflection zone with fully and partially equalised idlers.
- The arrest of lateral material migration with the Edge Brush system.

BACKGROUND

A brief background of the Sandwich Belt high angle conveyor development is presented here. The reader is referred to the 1982 landmark writing “Evolution of Sandwich Belt High Angle Conveyors”[1] a comprehensive presentation on the development.

Sandwich Belts of the 1950s

The concept of elevating bulk materials at high angles using the sandwich belt concept was first introduced in 1951. That introduction did not produce any lasting success. It did produce the mathematical model that facilitated calculation of the hugging pressure needed to develop the material’s internal friction so that material slide back did not occur when operating at the design steep incline.

Loop Belts of the 1970s

Commercial success in sandwich belt high angle conveying was achieved in the 1970s with the Loop Belts, sandwich belt elevators of C-shaped profile developed by Stephens Adamson of Canada. The Loop Belts were and are the vital elements of conveyor based self-unloading ship systems. Such self-unloading ships have had great success achieving unloading rates above 10000 t/h with wide Loop Belts to 3048 mm (120”). Being strictly of C-profile, Loop Belts could not be adapted to the general high angle conveying path which is predominantly along a straight incline.

Dos Santos Sandwich Belts of the 1980s

It was the success of Loop Belts that inspired the Dos Santos Sandwich Belts of the 1980s. These expanded the Loop Belt capabilities by producing endless elevating profiles that could take the most direct and/or conforming path between the loading and discharge points. This development was broad, rationalising the sandwich belt high angle conveyor technology in the conventional conveyor technology. Two inventions came out of this development, the Snake sandwich belt and the mechanically pressed sandwich belt. Whereas the former is a technological extension of the Loop Belts of the 1970s, the latter could be considered additionally the technological extension of the Cover Belts of the 1950’s. Figure 2 shows the Snake sandwich high angle conveyor concept and reality in the DSI Snake. Figure 3 shows the mechanically pressed sandwich high angle conveyor concept and reality in the DSI GPS (Gently Pressed Sandwich). Both systems use the basics of the Snake sandwich. An additional variation of the mechanically pressed sandwich allows for the use of steel cord belts in a very high single flight system. This is depicted in the last image of figure 1. Such a system uses a large uplift type transition curve that intrudes into the open pit. Very high single lifts exceeding 300 meters are possible.

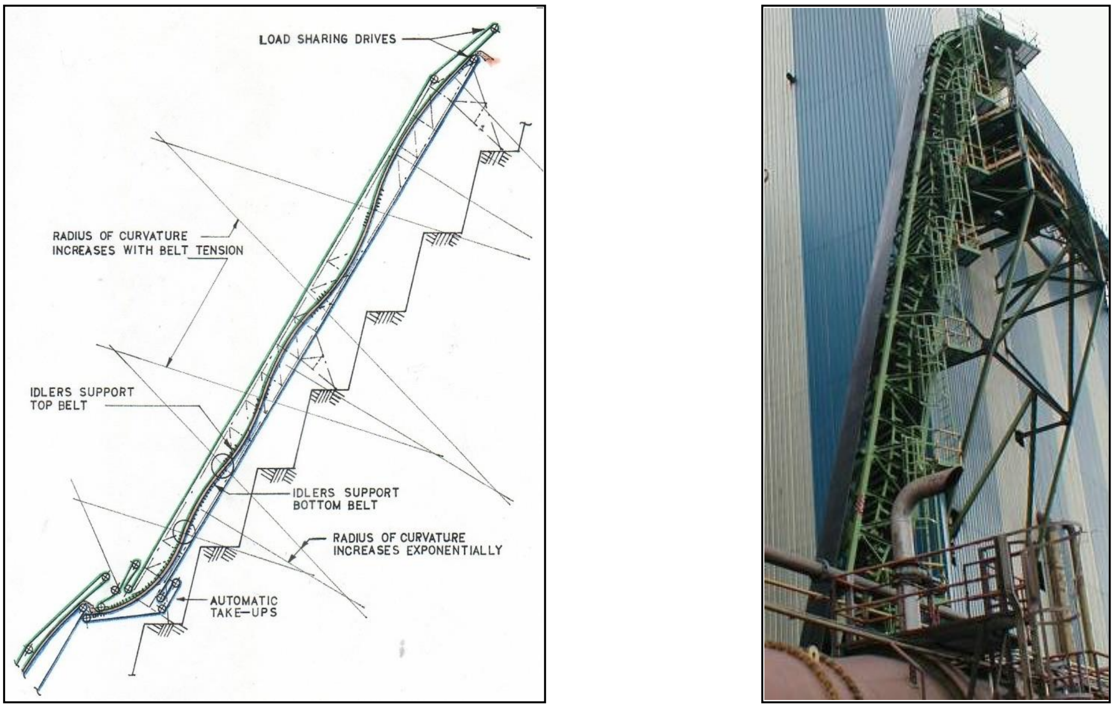

Figure2 – Snake Sandwich, from concept (left) to reality (right)

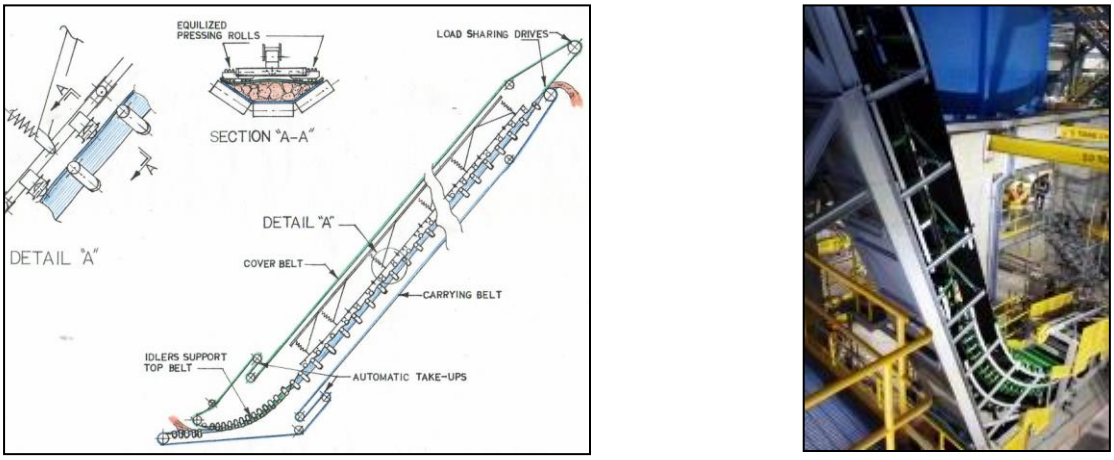

Figure 3 – Mechanically Pressed Sandwich, from concept (left) to reality (right)

Both Snakes and GPSs typically use the same transition features in increasing the conveying angle from the low angle at the loading point to the ultimate high angle. A transition curve is also typical from the high incline angle to the discharge. The former uses two convex curves after the top belt joins the bottom belt forming the sandwich. The first convex curve is carried along closely spaced inverted troughing idlers. The second reverses the curvature and is carried along closely spaced upright idlers to the straight high angle incline. An inflection zone between the two curves transitions the sandwich smoothly from the inverted troughing to the upright troughing configuration. The Snake differs from the GPS only along the straight incline. The former continues using alternating convex curves with inflection zones between the curves. The latter uses a straight high incline with fully equalised pressing rolls applying a gentle hugging pressure onto the top belt which in turn hugs the bulk material onto the lower troughed belt.

HYBRID SNAKE AND GPS

Previous Sandwich Belt high angle conveyors have either been Snakes or GPS units. The technology however does not limit the profiles and combining the two in a single profile makes sense when that combined profile best fits the geometrical requirement. Such is the case in this latest hybrid installation which is depicted in Figures 4 and 5. A technical summary is presented in Table 1.

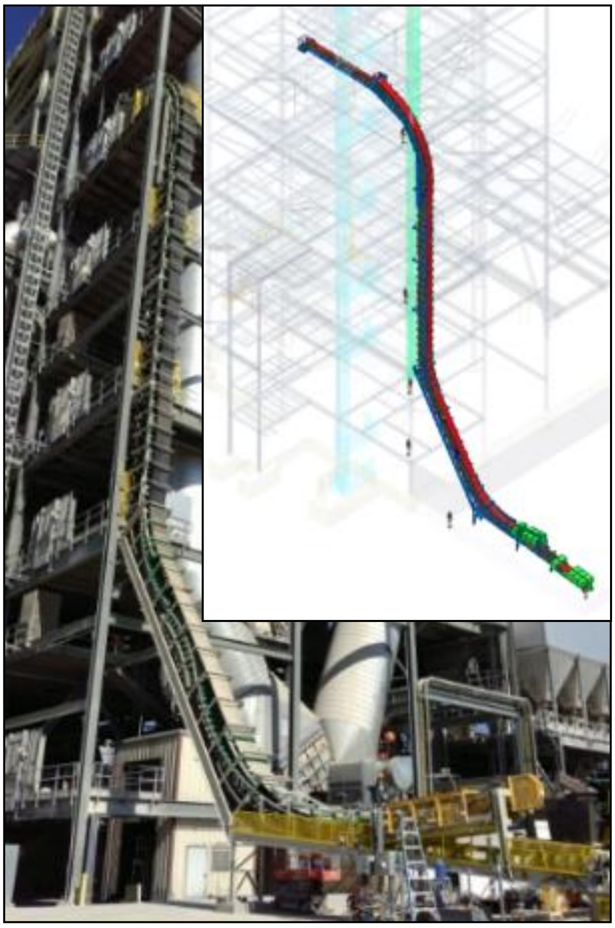

Figure 4 – DSI Hybrid Snake/GPS unit lifts shredded tires to fuel the boiler at the plant

Material	- Tire chips
- Density	- 0.40 t/cu-m (25 PCF)
- Size	- 50.8 mm (2”) minus
Conveying Rate	- 9 t/h (10 STPH)
Conveying Angle	- 55/90 degrees
Belt Width	- 762 mm (30”)

Belt Speed	- 0.50 m/s (100 FPM)
Lift	- 40,538 mm (133’)
Length	- 67,056 mm (220’)
Snake Drives	
- Top Belt	- 5.6 kW (7.50 HP)
- Bottom Belt	- 5.6 kW (7.50 HP)

Table 1 – Technical Summary DSI GPS Sandwich Conveyor, Texas, USA

Cement plants are very energy intensive requiring both electrical power and heat. Abundant and cheap fuel is essential to the operation of any cement plant. Worn and damaged, discarded tyres offer such a cheap fuel while solving an environmental problem as the tyres would otherwise be dumped in the municipal landfills.

This Texas cement plant was already burning whole tyres for fuel. Studies and experience revealed that shredding the tyres exposed much more surface area and resulted in more efficient, complete burning with less ash waste.

The site allowed ample space for the shredding system including storage space as the shredding capacity exceeded the instantaneous plant needs. A front end loader transported the excess shreds to the storage area then back to the feed circuit when needed.

The site also provided ample paved space for vehicular movement but the lower approach path of a typical vertical high angle conveyor would block the traffic path to the plant, hence the hybrid Snake/GPS. Typically, the approach of a vertical DSI GPS consists of the open troughed bottom belt until it is joined by the top belt to form the sandwich. From that point the Sandwich conveyor incline is increased to vertical along a convex transition curve which is carried by closely spaced inverted troughing idlers. Such an arrangement would block traffic access from the shredding yard to the plant. The chosen solution was to begin the high angle ascent sufficiently before the building face then ascend vertically along the wall. A 55 degree ascent to the building face did the trick, easily exceeding the required 6.15m width x 4.27m height clearance envelope. Layout determined that this lower ascent was best achieved with an additional upright convex curve between the lower inverted transition curve and the subsequent inverted curve to the vertical ascent. Along the vertical ascent the GPS (Gently Pressed Sandwich) approach was chosen for its compactness and conformance. Two additional convex curves at the top transition the profile from vertical to the horizontal discharge of the bottom belt. The top belt departs tangentially from the uppermost transition curve at 20 degrees to its drive pulley.

Figure 5 – Left: Background shows shredder system and storage pile. Right: Close–up of tyre shreds in storage pile.

This system has proven to be very successful and promises to revolutionise vertical haulage of shredded tyres to the boiler at many future cement plants.

PATENTED ADDER SNAKE

The patented Adder Snake is the invention of Marcus J. dos Santos. It was presented at Beltcon 20. The reader is referred to the Beltcon 20 paper "Adder Snake: Low-Angle to High-Angle with no Transfers"[2] for a thorough description. The system is described here briefly followed by an example of its merits in an overland downhill conveyor application.

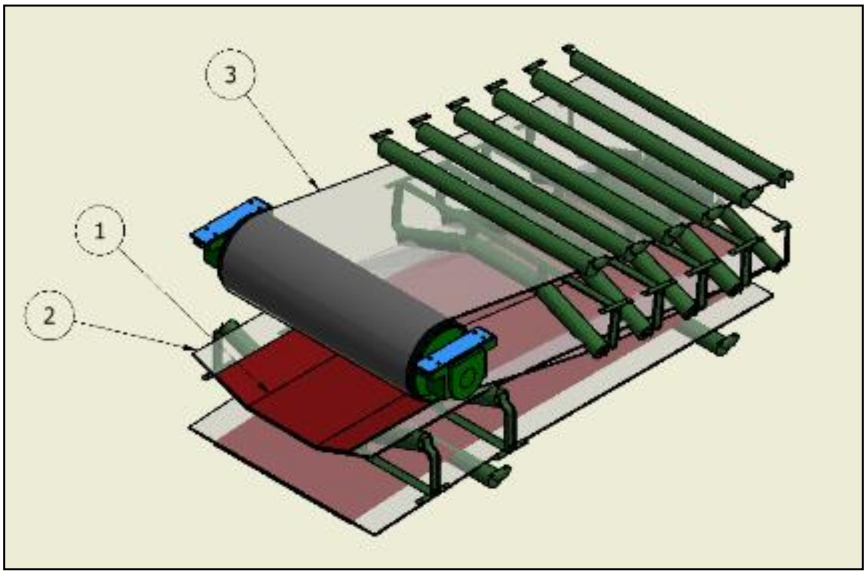

Figure 6 – Adder Snake generalised sandwich entrance - conventional belt in red; Sandwich belts semi-transparent

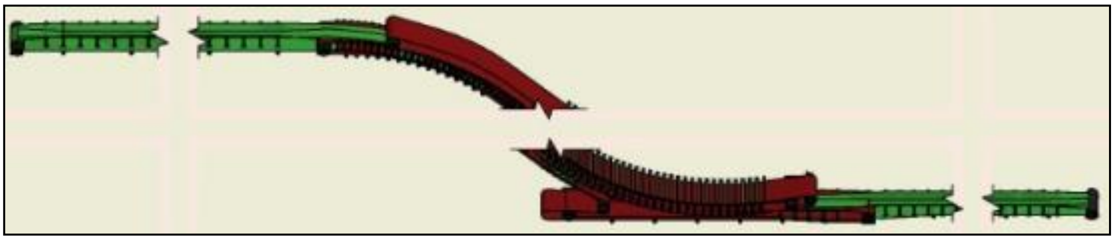

Figure 7 – Adder Snake generalised layout – conventional belt in green; Sandwich belts in red

The basics of the Adder Snake are presented in Figures 6 and 7. The system optimises economics by exploiting the advantageous features of the conventional conveyor within its low incline angle limitations and the Sandwich Belt high angle conveyor, with its ability to convey material at any high angle. By swallowing the conventional conveyor with its bulk load the Sandwich Belt high angle conveyor can carry the belt and its load along a high angle incline to discharge or to a lower angle where the conventional conveyor continues on its way to the ultimate discharge. The Beltcon 20 writing describes the occurrences and circumstances that inspired the invention then presents specific cases where the Adder Snake offers particular advantage:

- At an underground silo reclaim conveyor, the Adder Snake facilitates the abrupt upturn of the conveyor belt line to discharge at a high elevation to alternate outgoing collecting conveyors on the surface.

- At a tripped dock belt to a ship loader, the Adder Snake elevates the dock belt and its bulk load along a high angle incline to discharge onto the ship loader's boom conveyor. In a new system, this offers great savings in the reduced dock length. In an existing system, it makes more of the dock length available for ship loader travel facilitating the loading of bigger, longer ships.

Overland Downhill Adder Snake/GPS

In 2019, a project in Russia presented a unique opportunity to demonstrate the capability and advantages of the Adder Snake. The project required the overland transport of coal from the plant storage, 318 meters, lifting 13 meters to the edge of a coastal cliff then down, 48 meters of drop to a dock conveyor that delivered the coal to a ship loader. The volumetric transport requirements were significant at 4667 m^3/h requiring a 2000 mm wide overland Adder Belt and 2400 mm wide Sandwich Belts running at 4.2 m/s. The material size is also large at up to 300 mm but this is not a problem for the wide belts that are required for the design rate. The Adder Snake/GPS solution is illustrated in Figure 8 with a technical summary in Table 2.

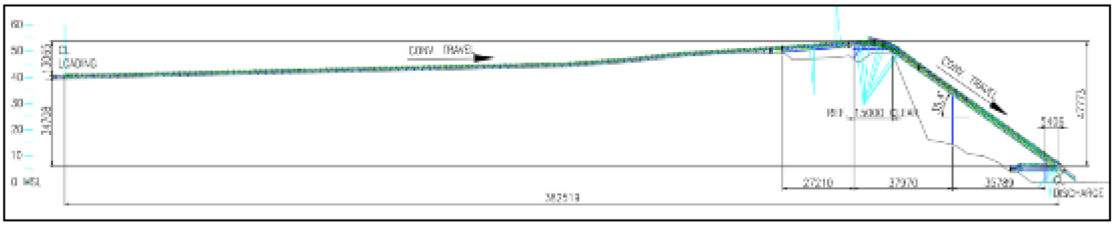

Figure 8 – Adder Snake/GPS for Russian project, conveying coal from the plant, over a coastal cliff, down to a dock conveyor

Material	- Hard Coal
- Density	- 0.75 t/cu-m (46.8 PCF)
- Size	- 300 mm (11.8") minus
Conveying Rate	- 3500 t/h (3858 STPH), - 4667 cu-m/h
Conveying Angle	- 35.4 degrees
Belt Width:	
- Sandwich	- 2400 mm (94.49")
- Adder	- 2000 mm (78.74")
Belt Speed	- 4.20 m/s (827 FPM)

Elevation Drop	
- Net.	- 34,708 mm (113.9')
- Max. Diff.	- 47,773 mm (156.7')
Length	
- Sandwich Conv.	- 97,054 mm (318.4')
- Adder Conv.	- 401,131 mm (1,316.0')
Snake Drives	
- Top Belt	- 250 kW (335 HP)
- Bottom Belt	- 250 kW (335 HP)

Table 2 – Technical Summary DSI Adder/GPS Sandwich Conveyor

The calculated power running at design load full length is -125 kW, so when running loaded the system generates 125 kW of electrical power that is fed into the electrical grid. The transient power requirements are much higher. As the empty running conveyor is loaded at design rate its power draw increases from 146 kW to a high of 395 kW when the loaded length reaches the highest elevation. It then reduces to 125 kW (regeneration) when running loaded over the full length. When the loading is cut off the power reduces to its lowest (highest regenerative) -250 kW when the remaining load is only along the downhill portion of the profile. All calculations thus far are based on normal friction and this will tend to overstate the travel resistances, and thus possibly understate the regenerative power values. To size the drives the max regenerative power must be calculated based on reduced friction and factor up. This is to ensure that a runaway conveyor will not occur in the case of trailing off with a load that may exceed the design load. Such calculations led to selecting 2x250 kW=500 kW of conveyor connected power.

From the loading point to the sandwich entrance, the 2000 mm wide Adder conveyor is carried on 35 degree troughing idlers. The Sandwich conveyor that envelops the Adder with its bulk is a GPS (Gently Pressed Sandwich) type of high angle conveyor. It begins with the lower belt that is initially troughed at 27.5 degrees then goes into a downward convex curve that is carried on closely spaced 20 degrees troughing idlers. The upper belt joins the lower belt along the convex curve forming the sandwich. The curve continues until reaching the downward high angle of 35.4 degrees. From that point it descends along the straight profile to discharge, carried on 35 degrees troughing idlers while the upper belt is urged onto the bulk and lower belt by the fully equalised rolls of the GPS pressing modules.

The drives in this case are only at the respective tail pulleys of the lower and upper Sandwich Belts. The Adder is not driven by its own power.

All three belts are tensioned independently by hydraulic tensioning cylinders. All take-ups are at the bottom of the profile, immediately after the material discharge.

From the loading point to the Sandwich, the overland Adder is of simple, clean and economical construction consisting of channel stringers on concrete ties that rest on a graded earth path. Access to the equipment is merely by walking on the earth path along either side of the conveyor.

Construction becomes more complex approaching and at the Sandwich conveyor. Project specifications required that structural support foundations not be closer than 15 meters from the cliff's edge. Additionally, there is a significant dip in the topography approaching the cliff. Drop off from top of the cliff is significant at 68 degrees. The discharge over the dock conveyor however is horizontally 64 meters from the cliff's edge. The best solution was to span over the cliff then to descend at a straight incline to the discharge point. This would minimise the environmental disturbance. The horizontal distance from the upper support point (which is 15 meters clear of the cliff's edge) to the discharge point is thus 79 meters.

The structural solution is illustrated in Figure 8. It consists of a minor approaching truss that carries the Adder conveyor into the Sandwich, then a major truss that carries the Adder and Sandwich conveyor to the discharge point. To optimise economics of the major truss, two (2) vertical bents reduce the structural spans to 38 meters and 36 meters. The modest foundations of the bents make a minimal environmental impact while facilitating significant savings in the steel construction.

PATENTED TBM TRAILING SANDWICH BELT HIGH ANGLE CONVEYOR

Dos Santos International has been awarded patents for their newest development in Sandwich Belt high angle conveying technology for tunnelling, the DSI TBM Trailing Sandwich Belt high angle conveyor. The first patent was awarded on October 19, 2021. A second patent that broadened the invention and expanded the claims was awarded on November 1, 2022. Joseph A. Dos Santos is the inventor.

Figure 9 – Conventional TBM trailing conveyor at the Paris Metro project.

The invention is to haul material away from continuous mining machines and, more particularly, from a TBM (tunnel boring machine) along any high angle incline.

In a typical mining operation such as tunnelling, it is well known to use a continuous mining machine, such as a TBM, to advance the mine face continuously without interruption. The rock material or muck must be hauled away continuously from the face. The conventional, open troughed extendable trailing conveyor (see Figure 9) has traditionally fulfilled this function as typical tunnel excavations are not along steep inclines.

Occasionally a tunnel must be excavated along a steep incline exceeding 15 to 18 degrees. A TBM is capable of such steep excavation, but the traditional open trough conveyor cannot serve the muck clearance function as the muck would slide down on the belt at such angles. Dos Santos Sandwich Belt high angle conveyors are well developed and well known to have the operating characteristics of conventional open trough conveyors, but they also have the capability of conveying the bulk at any high angle. This is done by sandwiching the bulk between two belts, hugging the material continuously (without lapse) in order to develop its internal friction which resists any tendency to slide down. The DSI invention extends the high angle capability to the TBM trailing conveyor.

In 2019, the challenge was presented to Dos Santos International. A major tunnelling project in Australia required the excavation to begin along a horizontal path then to increase in slope to 25 degrees. The 25 degree slope continued 1163 meters then again reduced to a lower, near horizontal angle along the remainder of the tunnel. Necessity being the mother of invention, DSI embraced the challenge. Some key elements of the invention were determined in the requirements of this project but not all. A summary of the requirements is presented here:

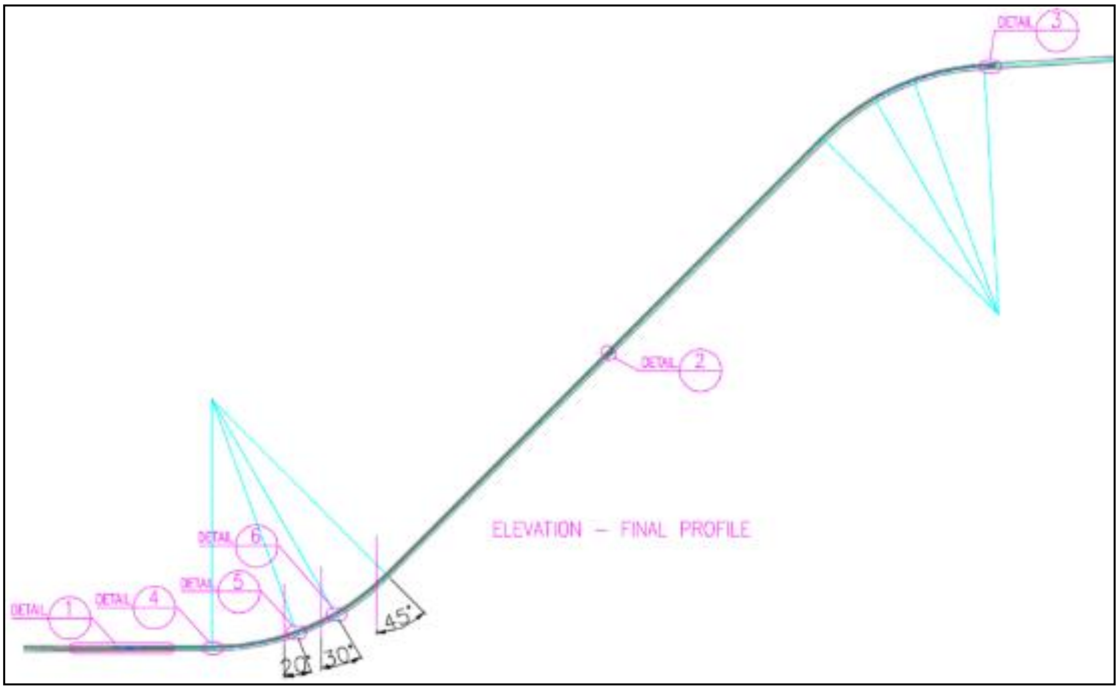

Figure 10 – Basis tunnel profile to illustrate the invention. Incline angle is illustrated at 45 degrees but the invention allows higher incline angles to 90 degrees

- The conveying system must begin at the launch of the TBM and must continue to haul the muck to the discharge point that is established at the launch.
- The loading point must be on the TBM trailing deck.
- The system must extend in length while in operation as the TBM advances the tunnel excavation.
- This requires a belt storage unit at the launch for both the top belt and for the bottom belt of the Sandwich conveyor.

This also requires that conveyor structure is added safely at the tunnel, from the TBM trailing deck as the Trailing Sandwich conveyor extends with the excavation.

Whereas the use of the belt storage units (one at each belt) is relatively straightforward, as is the loading at the TBM trailing deck, the transition from the low loading angle (onto the bottom belt) to the sandwich, then to the high angle is not.

Indeed, it is unprecedented. Traditionally the transition from the sandwich entrance to the high angle has been gradual along a convex transition curve. Such a curve is not possible within the space of the straight tunnel. The transition is thus abrupt. The skirted, flat bottom belt with the bulk load travels into the sandwich over a large diameter bend pulley that immediately deflects the belt line to the high angle. The top belt joins the bottom belt at the high incline covering the material stream immediately, imposing only a gentle hugging pressure onto the bulk material.

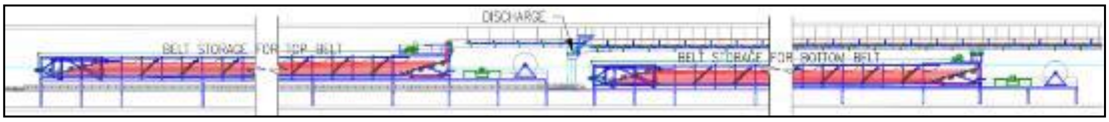

Figure 11 – Belt storage units, one at each belt, pay out belting as the TBM advances and the Sandwich Belt Trailing Conveyor lengthens.

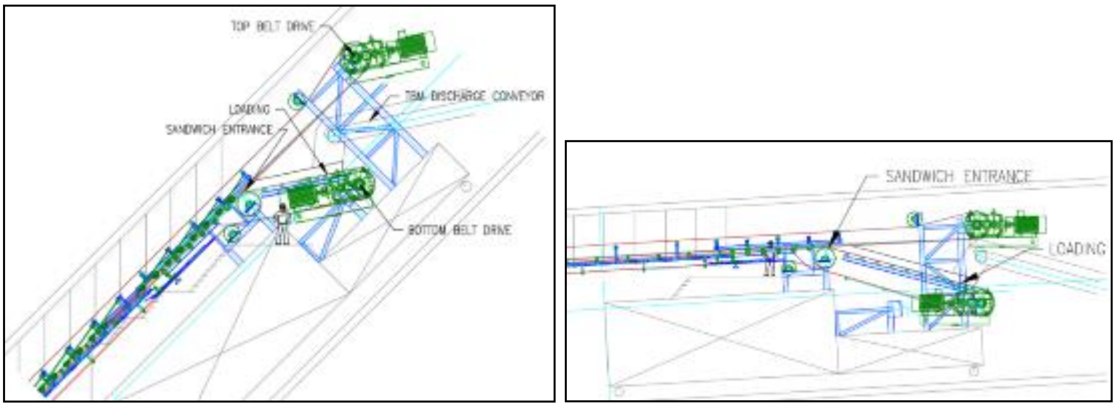

Figure 12 – Tail loading and drive station at the TBM trailing deck. TBM is excavating along the high incline at left and along a low angle at right.

The challenge of the 2019 Australian project inquiry prompted the invention but vision of the broader requirements, including much higher tunnel angles, formed the basis for the broader invention.

Most challenging of the broader higher angle requirements is the need for an interim hugging pressure as the permanent high angle structure is added from the TBM trailing deck. This is because the conveyor is running without lapse so the material hugging must also be without lapse. This challenge does not occur at conveying angles up to approximately 30 degrees as the contact and mere weight of the top belt stabilises the bulk load and develops its internal friction, typically up to the tangent of the material's angle of repose. This also means that at high angles to approximately 30 degrees, GPS (gently pressed sandwich) type pressing rolls are not required and the mere top belt suffices.

The interim hugging is accomplished with an air plenum type weighted blanket over the top belt for conveying angles of approximately 30 to 55 degrees and torsionally sprung air plenums for incline angles above say 55 degrees. In either case, the interim hugging system is secured to the high angle structure of the TBM trailing deck and creates a smooth upper surface that the permanent GPS pressing rolls can roll over and onto the top belt as they assume the permanent hugging function. Figure 13 presents a series of six slides that depict adding the permanent conveyor structure as the TBM advances, leaving the tunnel anchored hanging structure behind.

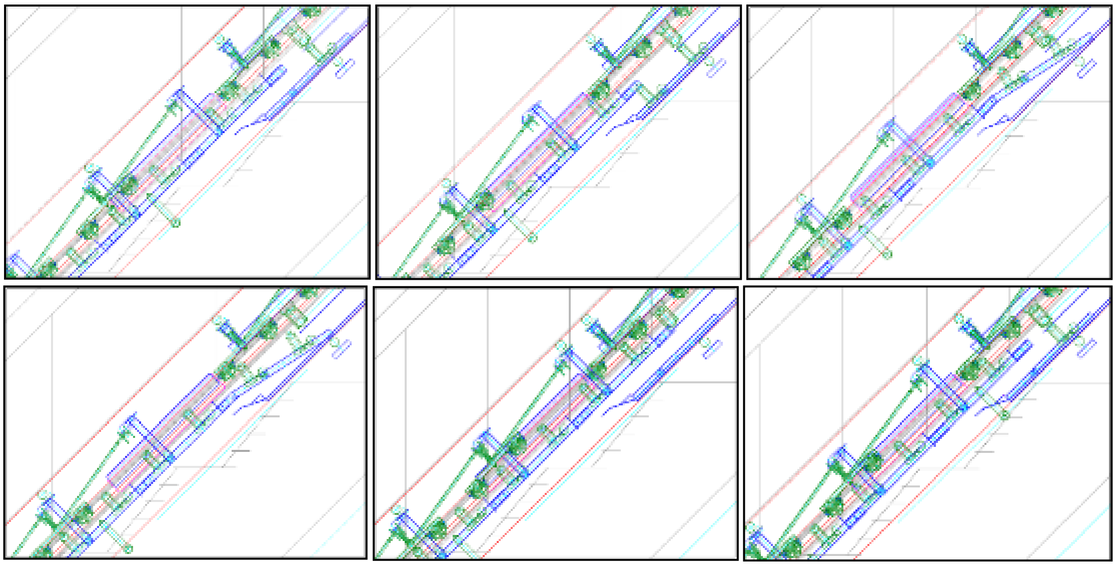

Figure 13 – Sequence, adding chain hung Sandwich conveyor structure at the tunnel from the TBM trailing deck.

The invention promises to revolutionise haulage from high angle tunnel excavations affording all of the benefits of TBM trailing conveyors that were not previously available at high incline angles.

BASICS OF CONVEYOR GEOMETRY

Neutral Axis Belt Line

Early in the writer's career the engineering director (his boss) shared his frustration with a conveyor transition from troughed to flat over the head/discharge pulley. Due to its tension the empty belt was lifting off of the several troughing idlers at the end of the conveyor, approaching the pulley. The several idlers had to be shimmed up into contact with the underside of the empty belt. This occurrence was routine and the higher the tension the longer the uplift distance thus the number of idlers that had to be shimmed.

Following the unexpected discussion, the writer returned to his desk and dug into the conveyor characteristics hoping to determine the cause of the uplift. Though many of the conveyor characteristics are long forgotten those that are important to uplift issue are not. The conveyor was carried on 3-equal-roll, 35 degrees troughing idlers. The transition was in conformance to CEMA (Conveyor Equipment Manufacturers Association) recommendations for a high-tension discharge transition with the top of the pulley placed in line with the mid-depth of the belt trough. Knowing this, the cause of the uplift became clear. The neutral axis of a 3-equal-part troughed belt is located 1/3rd the trough depth up from the bottom of the trough. As the neutral axis is the tension axis, lifting the top of the discharge pulley to ½ the trough depth represented a lifting of the tension line the amount of 1/6th the trough depth. In fact, the vertical misalignment is a bit more than 1/6th the trough depth because the middle of the belt is wider than 1/3rd of the belt width (actually 0.371xBW + 0.25") and the wings are each slightly less than 1/3rd of the belt width. Indeed, the ½ depth transition is incorrect as the belt will always lift up from the erroneously intended belt line, obviously when running empty and over a less obvious distance when running under variable load. Lifting the idlers into contact when running empty merely invalidates the ½ depth transition and realises an approximately (less than) 1/3rd trough depth transition. Of course, the latter negates the intended advantage of the ½ depth transition; a shorter transition that doesn't overstress the belt edges.

From that day, the writer pointed out the error whenever the discussion came up including on some on-line forums.

In 2013, Dos Santos International joined CEMA. At the first DSI attendance of the Annual Engineering Conference the writer brought up the issue, pointing out that the CEMA guidelines for the high-tension transitions had been wrong ever since the founding of the organisation, explained the mechanics of the error and was pleased to find the explanation was generally accepted. The CEMA book committee began making plans to get the matter corrected and published in the next edition (7th Edition) of the CEMA book "Belt Conveyors for Bulk Materials"[3].

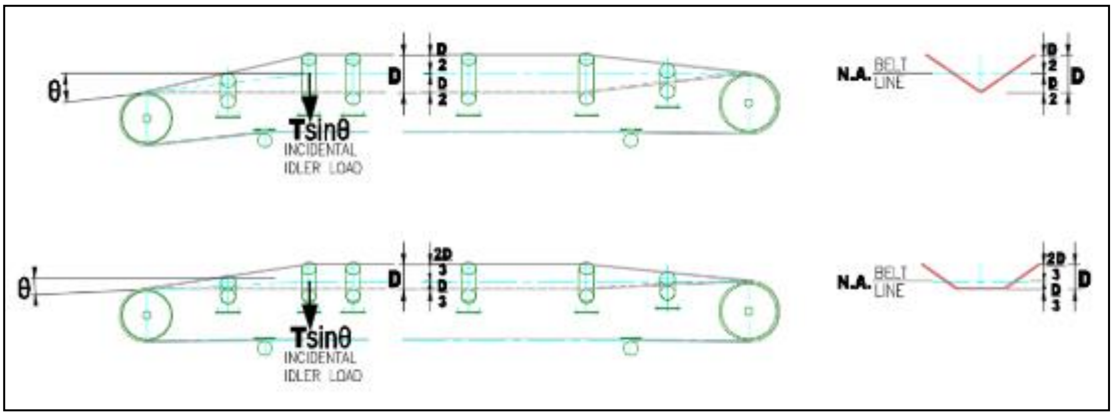

Figure 14 – Sketches above illustrate the location of the neutral axis belt line for two troughing configurations; 2-roll V-troughing and 3-equal-roll troughing

A write-up was submitted for the publication along with the sketches of Figure 14. To emphasise the importance of the neutral axis belt line Figure 14 included a 2-roll V-troughing as well as a 3-equal-roll troughing configuration because indeed in the former case the neutral axis is along the ½ depth of the trough. More generally the neutral axis is easily calculated for any troughing configuration including 3-roll troughing idlers with long middle roll or short middle roll, five roll troughing idlers, etc. All of these troughing configurations and more are used for their various advantages. More importantly, following the neutral axis conveyor line reveals the implications of the conveyor path. It was following the neutral axis belt line that revealed the error of the ½ trough depth transition for a 3-equal-roll troughing configuration. In Figure 14, following the neutral axis belt line in the case of a full trough depth transition (typically used at the transition from tail pulley to troughed) reveals the incidental deflection load onto the first troughing idler. So, the neutral axis belt line is a more intuitive basis for defining the conveyor line. Unfortunately, most of the industry uses the top of the middle roll, which is also the underside of the troughed belt, as the reference belt line.

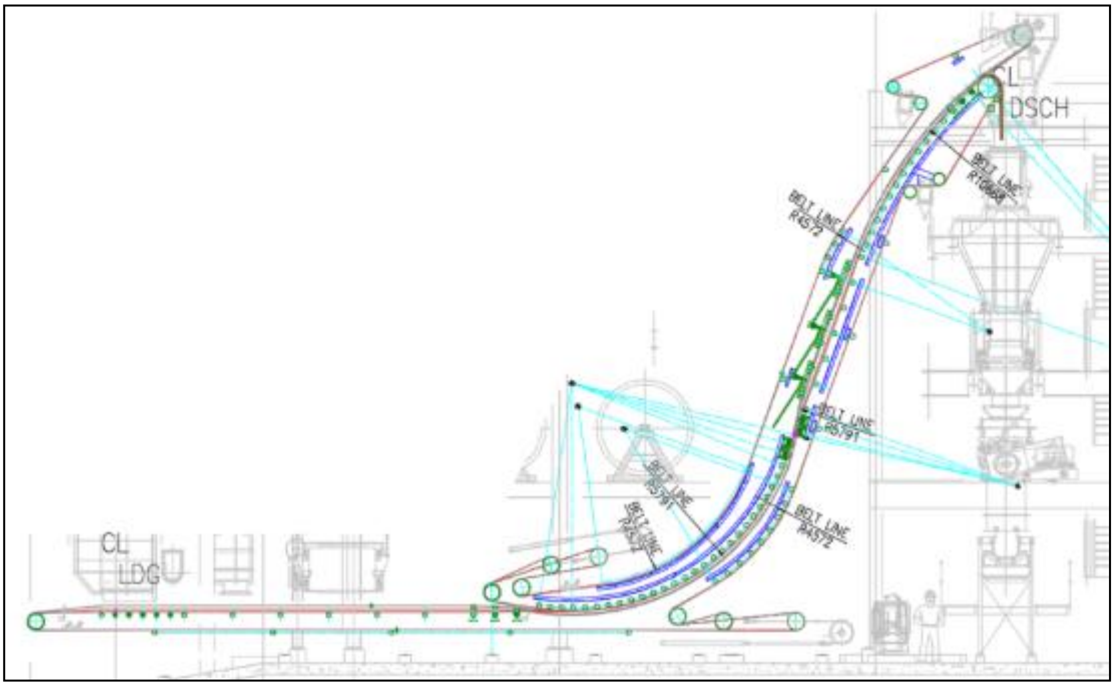

Figure 15 – A Neutral Axis belt line layout of a GPS Sandwich Belt conveyor is defined by smooth continuous curves and lines without abrupt deflections.

In the development of the Sandwich Belt high angle conveyor technology it was only natural to use the neutral axis belt lines of the top and bottom belts as the basis for representing the belt line geometry. This provided the smoothest and most intuitive belt lines when considering the transitions from trough to flat at the pulleys, the convex transition curves, as well as the straight paths and the various troughing configurations along the way. This facilitates the easy calculation of the radial loads that are due to the belt tension and the curvature. Figure 15 shows a simple neutral axis belt line layout of a DSI GPS Sandwich Belt high angle conveyor. So it was natural to extend the same practice to the conventional conveyor belt path. Dos Santos International engineers have always used the neutral axis belt line as the basis for representing the conveyor profile and path of the conventional conveyors as well and the industry is urged to adopt this practice.

Various Troughing Configurations and Capacity

It has been mentioned that the neutral axis is easily calculated for any troughing configuration, it is merely along the centre-of-gravity of the belt's axial stiffness and strength. The troughing configuration determines the radius of curvature pursuant to the radius of curvature constraint equations. Radius of curvature constraints are derived and explained in great detail in the early writing, "Evolution of Sandwich Belt High Angle Conveyors"[1]. To achieve the desired compactness of the high angle conveyor profile the most common troughing configuration along the convex transition curves is formed by closely spaced 3-equal-roll 20 degrees troughing idlers. The bulk load cross-section in the sandwich in this case was first determined by layout then confirmed and factored according to the results of extensive testing with many different bulk materials at a large-scale prototype unit that was built in 1983, ahead of commercialisation. The many commercial installations have largely validated the testing and the capacity rules.

There are occasions when the desired (or needed) very compact transitions cannot be achieved with a 3-equal-roll 20 degrees trough and the depth of the trough must be reduced. Such is the case with very small profiles as is common in municipal sludge handling and, at the other end of the spectrum, in self-unloading ship systems where very wide sandwich belts, typically of C-profile are used to deliver very high volumetric rates from the bottom of the ship's holds to the discharge boom conveyor on the ship's deck. In the latter case belt widths are typically 2000 mm to 3000 mm and the required lift is in the 18 metre range.

The trough depth may be reduced by reducing the troughing angle of the 3-equal-roll troughing idler or by keeping the 20 degrees troughing angle but with a long middle roll and short wing rolls. It can be a combination of both. Indeed, all such variations have been implemented including the very wide and shallow trough formed with "picking idlers".

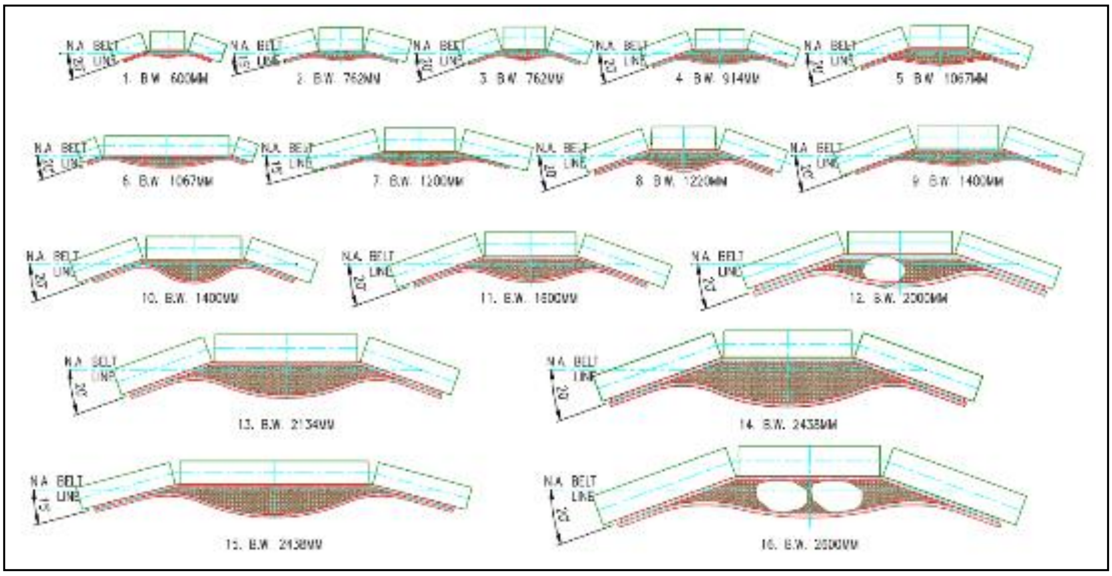

Figure 16 – Various troughing configurations along the lower convex transition curves are shown to a common scale. They are numbered for reference.

Figure 16 illustrates to a common scale the various troughing configurations along the lower convex transition curves. The sections are numbered for easy reference in this discussion. Section 2 shows that a 15 degree troughing angle is used at a small belt width (762 mm) to decrease the trough depth and facilitate a tighter transition curve. The tighter curve was needed to fit the Sandwich conveyor profile within the very limited space. Indeed, in the early days a very small installation elevating municipal sludge used 5 degree troughing 3-equal-roll troughing idlers along the transition curves. Several other installations used 10 degree 3-equal-roll troughing idlers. Section 6 shows an extreme case where picking idlers are used to facilitate a very tight transition curve at a Sandwich conveyor of C-profile that elevates hog fuel (sawdust, bark, chip rejects) to the main conveyor that delivers the fuel to the boiler at a pulp mill in Maine, USA. The neutral axis in this case is less than belt thickness from the flat of the trough's middle. Section 7 shows that a 15 degrees troughing angle at the 3-equal-rolls of the lower transition is used to facilitate the needed tighter transition curve. In the case of section 10, a longer middle roll with shorter wing rolls is used to achieve the desired reduced troughed depth in order to facilitate a tighter lower transition curve within the vertical shaft at the Paris Metro Expansion project. The increased length of the middle roll is modest in this case, just enough to achieve the desired transition curve. Likewise, section 13 uses a slightly longer middle roll compared to the wing rolls at a very wide conveyor to elevate various grains. Finally, section 15 shows both the use of a long middle roll with short wing rolls and a reduced (15 degrees) troughing angle in order to facilitate a very tight convex transition curve at a C-profile Sandwich Belt conveyor. The C-Sandwich is to continuously elevate the bulk material from under the ship's holds to the discharge boom conveyor which is on the ship's deck.

The rules for carrying capacity were originally developed for the sandwich carried by the inverted trough formed by 3-equal roll, 20 degrees troughing idlers. Layouts led to the basic material cross-section that is defined by the resulting trapezoid when a flat line is struck between the CEMA standard edge distances (0.055BW+0.9"). The sandwich cross-section is typically depicted naturally as in Figure 16 but the basis for the filling area is a trapezoid. Extensive testing at the first large scale prototype unit validated the principle and the "Basic Area" when subjected to the factors revealed by the testing. Material factors were determined as some materials tended to heap more within the sandwich and others tended to have a flatter cross-section. Material factors varied from a high of 1.15 for woodchips to a low of 0.85 for soy beans. In addition to the material factor there is an angle factor. During testing for leakage it was determined that leakage from the edges, due to overload, occurred at less cross-sectional filling as the conveying angle increased. Accordingly, a de-rating was assigned for each degree of angle increase beyond 60 degrees.

These rules served well for many years as it was most common to use 3-equal-roll troughing idlers along the convex curves. The model was abandoned for a particular project at a pulp mill in Maine, USA that needed to use the ultra long middle roll picking idlers to accomplish a very tight transition convex curve. Indeed, the basis model left virtually no theoretical material cross-section. For this project, the first to challenge the basis model, (in 2012) a more logical cross-section as indicated at section 6 of Figure 16 was determined. Because the material handled was wood chips and bark, the easiest of materials, we proceeded with confidence. The project was a success.

The slightly longer middle rolls of sections 10 and 13 did not prompt a re-visit of the original model but section 15 did. At this point it was clear that a more realistic model was required to cover the range of troughing configurations. The solution to this was to develop a second order curve fit that passed through the A-basic of the original model, allowed for a reasonable carrying area in the case of the extreme of a long middle roll idler, that is a flat belt sandwich, and then passed through a third known value, the design rate of a sandwich conveyor that is known to operate well. For the last point reference was made back to the operation of a Stephens Adamson Loop Belt of 2591 mm (102") belt width that dated back to the 1970's. So, the new material section calculation was adopted without abandoning the proven validity of the original model for the trough of the 3-equal-roll troughing idlers.

Control Through the Inflections with FEIs then PEIs

The Dos Santos Sandwich Belt conveyors generally use alternating convex curves along the profile. In the case of the GPS system (Figures 3 and 15), an S-Profile uses a lowest transition curve followed by a second reverse curve just before the straight GPS part of the profile. In the case of the Snake Sandwich (Figure 2) there is a series of alternating convex curves from the beginning to the end. From one convex curve to the next, the curvature reverses and the troughed section of the lower curve must be reversed to the opposite troughed section of the next convex curve. This point of curvature reversal is referred to as the inflection point and the immediately adjacent area as the inflection zone. Through the inflection zone material hugging must be maintained without lapse and the trough must be reversed over a distance that does not overstress the belt edges or relax the middle. This area was of great concern during the early development at Dravo. A proposal was developed to prove the inflection zone ahead of committing to the development and commercialisation. The decision to not pursue the Sandwich Belt conveyor technology further was made by Dravo management before the proposal could be implemented.

The Dravo concern was not shared by the management of Continental Conveyor and in 1982 they authorised building a large scale prototype on the basis of the writer's proposed design. The inflection zone was first handled with four standard vari-troughing idlers; two positioned at each side of the inflection, along each transition curve. These idlers were shimmed and the wing rolls were adjusted to support and transition the belt sandwich from one side of the inflection to the other. From the standpoint of belt stresses through the inflection zone these are adjacent transitions from troughed to flat then to troughed again but inverted. More importantly radial hugging pressure must be maintained through the first curve then instantaneously at and through the next curve. Figure 17 shows the two vari-troughing idlers immediately adjacent to the inflection, pursuant to the original design. This inflection zone could indeed be adjusted for continuous hugging of the bulk but only for a chosen material fill level typically corresponding to the design rate. At lower rates down to empty running, the belt line becomes straight for a short distance between climbing tangents from the adjacent curves. With the proper adjustments the material conveyed through the inflection zone without leakage. A weakness of this system: it was not easily defined on paper and required expert adjustments in the field. Additionally, at the reduced rates down to empty, the belt contact with the wing rolls tended to be localised with corresponding local wear. This system served well for the first 15 years and 80+ installations.

At the founding of Dos Santos International marketing began immediately of the DSI Snake Sandwich high angle conveyor with its multiple curves and inflections. The inflection zone was revisited. For better roll to belt contact along the wing rolls a 5-roll vari-troughing idler was developed that allowed troughing adjustment only at the upper half of each wing roll maintaining the lower half at the 20 degrees troughing position. Otherwise, the operating characteristics and adjustment requirements remained similar to the original system. Half-wing vari-troughing idlers are shown at the inflection of Figure 18.

Figure 17 – left side: Original inflection zone with standard vari-troughing idlers.

Figure 18 – right side: Special 5-roll half-vari-troughing idlers at the inflection zone.

Figure 19 – left side: FEI's (Fully Equalised Idlers) at the inflection zone.

Figure 20 – right side: PEI's (Partially Equalised Idlers) at the inflection zone.

The inflection zone came under close scrutiny in 2007 when a Snake ship loader for the Port of Adelaide in Southern Australia was supplied. The ship loader elevated various materials from the dock level, over, and into the ship's holds. Initially the ship loader was successful with all but one of the bulk materials. Ilmenite sands (titanium ore) were very fine grain and very dry, kiln dried to below 0.5% max moisture, typically having 0.30% to 0.35% moisture. This material was very runny and tended to leak from the edges at the first inflection zone and beyond. Leaking began at low conveying rates because the short straight belt line between tangents of the adjacent curves did not offer a continuous hugging of the very runny material. The need to solve this hugging lapse became the mother of the invention, leading to the FEI (fully equalised idler). The FEI was a natural solution featuring 4-fully-equalised idler rolls on an idler base frame. Like the 4-fully-equalised rolls of each GPS pressing section, the FEI has no preferred shape and assumes the shape of the sandwich section, maintaining full contact and hugging pressure regardless of the conveying rate.

The FEI became a success, provided continuous hugging and facilitated reliable representation on the drawing board, minimising the previous need for expert set-up in the field. Observing the behaviour of the many FEIs that followed, it was observed that the primary equaliser remained static in operation. Consideration was given to eliminating the primary equaliser in favour of direct support of the secondary equalisers on the fixed frame, creating a PEI (Partially Equalized Idler). Figure 20 shows such a PEI at the inflection of a wide GPS system. Ultimately the move was made to PEI's (in 2014) at a DSI Snake supplied to a cement plant in Brazil. PEIs continued to offer all of the benefits of the FEIs with less complication and shorter length along the belt line.

EDGE BRUSH SYSTEM

During the early years, in 1991 a vertical Sandwich Belt conveyor was supplied for a cement plant at the Port of Melbourne in Australia. The plant received shipments of gypsum and steel mill slag. A mix of these two materials was ground in a mill to create a high-quality cement product. No firing was required to create a clinker because the steel mill slag was the clinker. The vertical Sandwich Belt conveyor received these materials, each alone or in a mix, and delivered them up to the grinding mill.

The gypsum was a very fine material while the steel mill slag was in the form of a coarse sand type material. It had been anticipated that the fine gypsum would prove to be the more challenging of the two bulk materials. It turned out not to be the case. Possibly because of its natural moisture, the gypsum handled very nicely in the sandwich belt on its way up to the grinding mill. The steel mill slag on the other hand tended to migrate towards the edges of the sandwich and to leak out. It was at this time that the benefit of wetting the carrying surfaces of the belts at their edges was first discovered. With only a minimal amount of moistening the contact with the bulk material at its edge effectively arrested the material's lateral migration. It was here that the first "Edge Brush" system was produced.

The basic Edge Brush system consists of two wetting cloths, that wet both edges of the conveyor belt. In a Dos Santos Sandwich Belt high angle conveyor typically both (top and bottom) belts are made lightly wet on the edges of the carrying surface by contact with the wet draped cloths as the belt travels past the cloths.

From this point forward the Edge Brush was always a consideration as it was not always certain how an untested bulk material might behave within the sandwich.

Addition of this tool prompted a revisit to results of the 1983 testing at the original large scale prototype Sandwich Belt system. Here were tested many of the materials that would be handled commercially, all successfully. It was during this testing that the rules of capacity were empirically determined for the various materials conveyed at increasing incline angles. Unfortunately, limited budget and foresight limited the number of materials tested. Performance with the materials tested became the basis for future materials that were not tested. It is worth noting that during that testing there was the occasion to handle frac sand, a spherical, granular sand that foretold the Edge Brush before it was discovered. This dry spherical sand tended to leak from the sandwich belt edges along the length. The magnitude of the leaking was miniscule. As there was no means of controlling this it was determined that frac sand was not suitable for conveying in a Dos Santos Sandwich Belt high angle conveyor. Following the 1991 success with the first Edge Brush system, frac sand was reclassified as conveyable in a Dos Santos Sandwich Belt.

Figure 21 – Edge Brushes; at bottom belt (left) and at top belt (right)

The next use of an Edge Brush system was 16 years later, in 2007 at the DSI Snake ship loader for the Port of Adelaide in Australia. Recalling the previous section, this is where the FEI (Fully Equalised Idler) was first developed to improve material hugging through the inflection zone. The FEIs reduced edge leakage of the mineral sands but did not eliminate it. The Edge Brush did.

This high value material was kiln dried to a specification of 0.5% maximum moisture. Sampling demonstrated that the actual moisture content ranged between 0.3% and 0.35%. Because of the material's specification the customer insisted that no additional moisture was allowed. It was demonstrated that the added water of the Edge Brush system was insignificant and did not threaten violating the material's moisture limit. The customer ultimately agreed and the system has operated successfully with all materials since 2007.

Since its development in 1991, the Edge Brush system has been utilised five times, to save the day in some cases and to improve performance in others.

In England, in 2013, an Edge Brush system came to the rescue at a DSI Snake Sandwich high angle conveyor system that elevated fresh formed sulfur prills to a storage silo.

Anticipating possible leakage, the Edge Brush was incorporated from the outset in 2014 as part of a DSI Snake that elevated the mill feed materials to a cement plant in Paraiba, Brazil. This was the first case of a deliberate design of the Edge Brush system so it included electronics that interlocked the Edge Brush's operation with the Snake conveyor operation.

The most recent use of the Edge Brush system in 2022 is at a grain handling DSI GPS Sandwich Belt conveyor on the Mississippi River near Baton Rouge, Lousiana, USA. Part of a floating mid-stream barge to ship transfer terminal the 2134 mm (84") wide

GPS elevates various grains at up to 2268 t/h from the bottom of a sampling transfer to an outgoing conveyor that delivers the grain to the ship loader. This Edge Brush system is shown in Figure 21.

A missed Edge Brush opportunity occurred in 2020 in the Netherlands. Here a DSI GPS Sandwich Belt system was provided at a ship loader to elevate fertilizer prills at 600 t/h from the tripper of the dock conveyor to the ship loader's boom conveyor. This bulk material had not previously been conveyed at any DSI Sandwich Belt application, except for small-scale tests using the DSI trade show model, which were accepted by the end user's representative. At start up the material tended to migrate laterally to the belt edges and leaked a minor amount of prills. A start-up routine was followed that attempted to virtually eliminate any leakage leaving the Edge Brush system to be the last resort. Indeed, it came down to the Edge Brush. This case had some parallels with the Ship Loader at the Port of Adelaide. In both cases the material specifications limited the moisture content to a maximum of 0.5%. In both cases the effectiveness of the Edge Brush system was demonstrated and that the added moisture was insignificant, less than 0.001%. Ironically the material leakage to be arrested was minor compared to that at the Port of Adelaide. The customer in Australia accepted the Edge Brush solution and has operated their Snake ship loader successfully since 2007. The customer in the Netherlands did not.

CLOSING

The modern Sandwich Belt high angle conveyor technology was developed by the writer from 1979 to 1981 then commercialised beginning in 1982. The record is one of success. Innovation has continued through the years fulfilling the promise of the "Broad Horizons" that were enumerated in the 1981 "memo to Dravo marketing". The innovations have been broad in scope as in the inventions of the Adder Snake and the TBM Trailing Sandwich Belt High angle Conveyor. They have been adaptive amalgamations as in the Hybrid Snake/GPS. They have been fundamental as in the Neutral Axis Belt Line basis for both Sandwich Belt high angle conveyors and conventional conveyors, and the rules for design capacity, both applied to the wide variation of troughing configurations. They have been local though no less significant in the improvements in the bulk material containment, through the inflection zones with FEIs and PEIs and arresting the lateral material migration with the Edge Brush system. Such innovation will continue into the future continuing the realisation of the promise of Broad Horizons.

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