

Latest Developments in Belt Conveyor Technology

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Abstract

Bulk material transportation requirements have continued to press the belt conveyor industry to carry higher tonnages over longer distances and more diverse routes. In order keep up, significant technology advances have been required in the field of system design, analysis and numerical simulation. The application of traditional components in non-traditional applications requiring horizontal curves and intermediate drives have changed and expanded belt conveyor possibilities. Examples of complex conveying applications along with the numerical tools required to insure reliability and availability will be reviewed.

Introduction

Although the title of this presentation indicates “new” developments in belt conveyor technology will be presented, most of the ideas and methods offered here have been around for some time. We doubt any single piece of equipment or idea presented will be “new” to many of you. What is “new” are the significant and complex systems being built with mostly mature components. What is also “new” are the system design tools and methods used to put these components together into unique conveyance systems designed to solve ever expanding bulk material handling needs. And what is also “new” is the increasing ability to produce accurate computer simulations of system performance prior to the first system test (commissioning).

As such, the main focus of this presentation will be the latest developments in complex system design essential to properly engineer and optimize today’s long distance conveyance requirements.

The four specific topics covered will be:

- Energy Efficiency
- Route Optimization
- Distributed Power
- Analysis and Simulation



Energy Efficiency

Minimizing overall power consumption is a critical aspect of any project and belt conveyors are no different. Although belt conveyors have always been an efficient means of transporting large tonnages as compared to other transport methods, there are still various methods to reduce power requirements on overland conveyors. The main resistances of a belt conveyor are made up of:

- Idler Resistance
- Rubber indentation due to idler support
- Material/Belt flexure due to sag being idlers
- Alignment

These resistances plus miscellaneous secondary resistances and forces to overcome gravity (lift) make up the required power to move the material.¹

In a typical in-plant conveyor of 400m length, power might be broken into its components as per Figure 1 with lift making up the largest single component but all friction forces making up the majority.

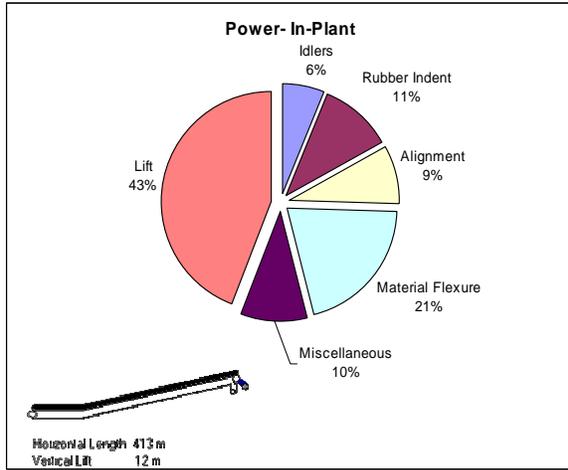


Figure 1

In a high incline conveyor such as an underground mine slope belt, power might be broken down as per Figure 2, with lift contributing a huge majority. Since there is no way to reduce gravity forces, there are no means to significantly reduce power on high incline belts.

But in a long overland conveyor, power components will look much more like Figure 3, with frictional components making up almost all the power. In this case, attention to the main resistances is essential.

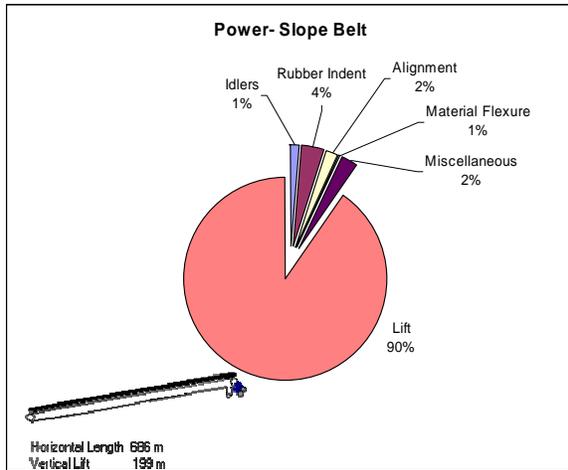


Figure 2

The specifics of power calculation is beyond the scope of this paper but it is important to note that significant research has been done on all four areas of idlers, rubber

indentation, alignment and material/belt flexure over the last few years. And although not everyone is in agreement as to how to handle each specific area, it is generally well accepted that attention to these main resistances is necessary and important to overall project economics.

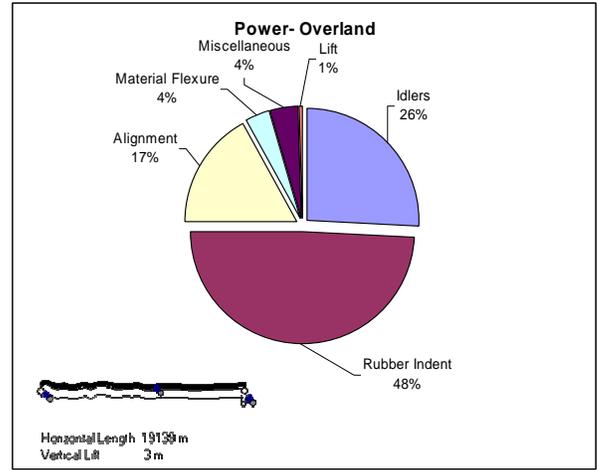


Figure 3

At the 2004 SME annual meeting, Walter Kung of MAN Takraf presented a paper titled “The Henderson Coarse Ore Conveying System- A Review of Commissioning, Start-up and Operation”². This project was commissioned in December 1999 and consisted of a 24 km (3 flight) overland conveying system to replace the underground mine to mill rail haulage system.



Figure 4- Henderson PC2 to PC3 Transfer House

The longest conveyor in this system (PC2) was 16.28 km in length with 475m of lift. The most important system fact was that 50% of the operating power (~4000 kW at 1783 mtph and 4.6 m/s) was required to turn an empty belt therefore power efficiency was critical. Very close attention was focused on the idlers, belt cover rubber and alignment. One way to document relative differences in efficiency is to use the DIN 22101 standard definition of “equivalent friction factor- f” as a way to compare the total of the main resistances. In the past, a typical DIN f used for design of a conveyor like this might be around 0.016. MAN Takraf was estimating their attention to power would allow them to realize an f of 0.011, a reduction of over 30%. This reduction contributed a significant saving in capital cost of the equipment. The actual measured results over 6 operating shifts after commissioning showed the value to be 0.0075, or even 30% lower than expected. Mr. Kung stated this reduction from expected to result in an additional US\$100, 000 savings per year in electricity costs alone.

Route Optimization



Figure 5- Tiangin China

Horizontal Adaptability

Of course the most efficient way to transport material from one point to the next is as directly as possible. But as we continue to transport longer distances by conveyor, the possibility of conveying in a straight line is less and less likely as many natural and man-made obstacles exist. The first horizontally curved conveyors were installed many years ago, but today it seems just about every overland conveyor being installed has at least one horizontal change in direction. And today’s technology allows designers to accommodate these curves relatively easily.

Figures 5 and 6 shows an overland conveyor transporting coal from the stockpile to the shiploader at the Tianjin China Port Authority installed this year. Designed by E.J. O’Donovan & Associates and built by Continental

Conveyor Ltd of Australia, this 9 km overland carries 6000 mtph with 4x1500 kW drives installed.

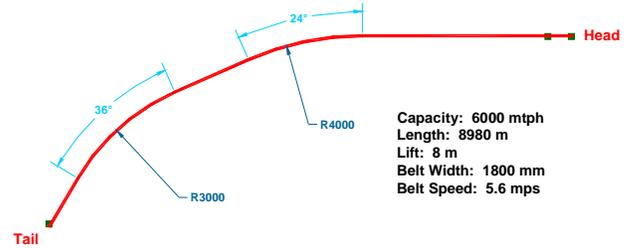


Figure 6- Tiangin China Plan View

The Wyodak Mine, located in the Powder River Basin of Wyoming, USA, is the oldest continuously operating coal mine in the US having recorded annual production since 1923. It currently utilizes an overland (Figure 7) from the new pit to the plant 756m long (2,482 ft) with a 700m (2,300 ft) horizontal radius. This proves a conveyor does not need to be extremely long to benefit from a horizontal turn.³



Figure 7- Wyodak Coal

Tunneling

Another industry that would not be able to use belt conveyors without the ability to negotiate horizontal curves is construction tunneling. Tunnels are being bore around the world for infrastructure such as waste water and transportation. The most efficient method of removing tunnel muck is by connecting an advancing conveyor to the tail of the tunnel boring machine. But these tunnels are seldom if ever straight.

One example in Spain is the development of a 10.9m diameter tunnel under Barcelona as part of the Metro (Train) Extension Project. Continental Conveyor Ltd. installed the first 4.7km conveyor as shown in Figures 8 and 9 and has recently received the contract to install the second 8.39 km conveyor.

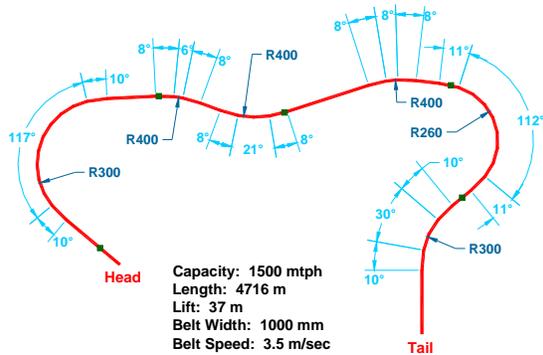


Figure 8- Barcelona Tunnel Plan View



Figure 9- Inside Tunnel

In another example, Frontier Kemper Construction is currently starting to bore 6.18 km (20,275 ft) of 3.6m (12 foot) diameter tunnel for the Metropolitan St. Louis (Missouri) Sewer District. The Baumgartner tunnel (Figure 10) will be equipped with a 6.1 km conveyor of 600mm wide belting with 4 intermediate drives.

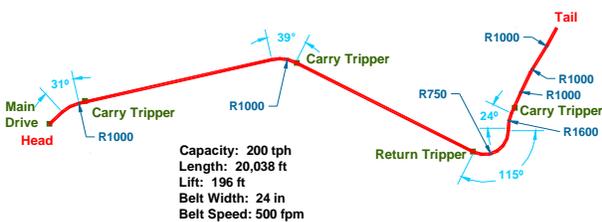


Figure 10- Baumgartner Tunnel Plan View

Pipe Conveyors

And if conventional conveyors cannot negotiate the required radii, other variations of belt conveyor such as the Pipe Conveyor might be used.

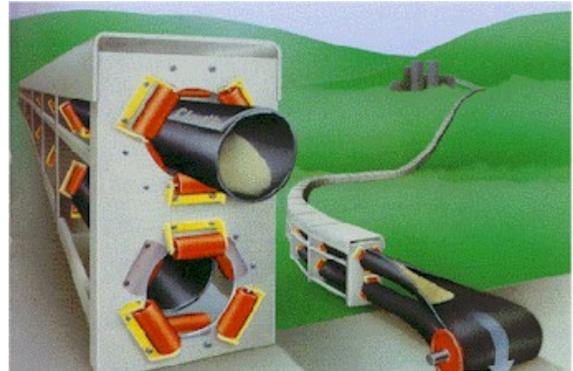


Figure 11- Pipe Conveyor

In its simplest description, a pipe conveyor consists of a rubber conveyor belt rolled into a pipe shape with idler rolls. This fundamental design causes the transported material to be totally enclosed by the belt which directly creates all the advantages.

The idlers constrain the belt on all sides allowing much tighter curves to be negotiated in any direction. The curves can be horizontal, vertical or combinations of both. A conventional conveyor has only gravity and friction between the belt and idlers to keep it within the conveyance path.



Figure 12

Another benefit of pipe conveyor is dust and/or spillage can be reduced because the material is completely enclosed. A classic example where both environment and adaptability to path were particularly applicable was at the Skyline Mine in UT, USA (Figure 12). This 3.38 km (11,088 ft) Pipe Conveyor was installed by ThyssenKrupp

Robins through a national forest and traversed 22 horizontal and 45 vertical curves.⁴

Metso Rope Conveyor

Another variation from conventional is the Metso Rope Conveyor (MRC) more commonly known as Cable Belt. This product is known for long distance conveying and it claims the longest single flight conveyor in the world at Worsley Alumina in Australia at 30.4 km. With Cable Belt, the driving tensions (ropes) and the carrying medium (belt) are separated (Figure 13).

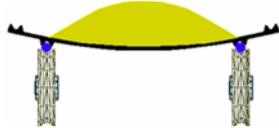


Figure 13- MRC- Straight Section

This separation of the tension carrying member allows positive tracking of the ropes (Figure 14) which allow very small radius horizontal curves to be adopted that defeat the traditional design parameters based on tension and topography



Figure 14

MRC vs. Conventional Conveyor in Horizontal Curve



Figure 15- MRC at Line Creek, Canada

Figure 15 shows a 10.4 km Cable Belt with a 430m horizontal radius at Line Creek in Canada.

Vertical Adaptability

Sometimes material needs to be raised or lowered and the conventional conveyor is limited to incline angles around 16-18 degrees. But again non-traditional variations of belt

conveyors have been quite successful at increased angles as well as straight up.

High Angle Conveyor (HAC®)

The first example manufactured by Continental Conveyor & Equipment Co. uses conventional conveyor components in a non-conventional way (Figure 16). The concept is known as a sandwich conveyor as the material is carried between two belts.

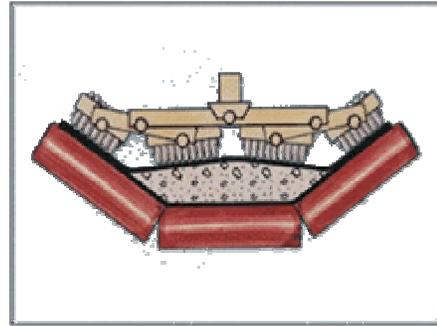


Figure 16

Continental's 100th installation of the HAC® was a unique shiftable installation at Mexican de Canenea's heap leach pad (Figure 17).



Figure 17

Pocketlift®

The second example shows a non-traditional belt construction which can be used to convey vertically (Figure 18).

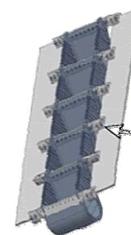


Figure 18

This Metso Pocketlift[®] belt was installed by Frontier Kemper Constructors at the Pattiki 2 Mine of White County Coal in 2001 (Figure 19). It currently lifts 1,818 mtpd of run-of-mine coal up 273 m (895 ft).⁵

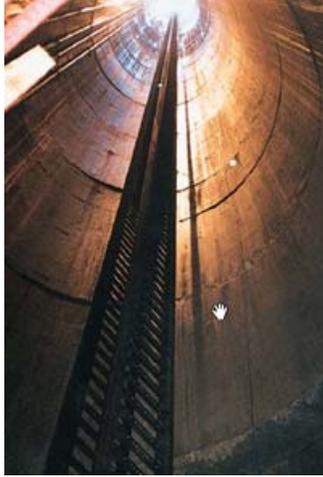


Figure 19- Pattiki 2 Mine

Distributed Power

One of the most interesting developments in technology in the recent past has been the distribution of power along the conveyor path. It has not been uncommon to see drives positioned at the head and tail ends of long conveyors and let the tail drive do the work of pulling the belt back along the return run of the conveyor. But now that idea has expanded to allow designers to position drive power wherever it is most needed.

The idea of distributing power in multiple locations on a belt conveyor has been around for a long time. The first application in the USA was installed at Kaiser Coal in 1974. It was shortly thereafter that underground coal mining began consolidating and longwall mines began to realize tremendous growth in output. Mining equipment efficiencies and capabilities were improving dramatically. Miners were looking for ways to increase the size of mining blocks in order to decrease the percentage of idle time needed to move the large mining equipment from block to block. Face widths and panel lengths were increasing.

When panel lengths were increased, conveyance concerns began to appear. The power and belt strengths needed for these lengths approaching 4 -5 km were much larger than had ever been used underground before. Problems included the large size of high power drives not to mention being able to handle and move them around. And, although belting technology could handle the increased strength requirements, it meant moving to steel reinforced belting that was much heavier and harder to

handle and more importantly, required vulcanized splicing. Since longwall panel conveyors are constantly advancing and retreating (getting longer and shorter), miners are always adding or removing rolls of belting from the system. Moreover, since vulcanized splicing takes several times longer to facilitate, lost production time due to belt moves over the course of a complete panel during development and mining would be extreme. Now the need surpassed the risk and the application of intermediate drives to limit belt tensions and allow the use of fabric belting on long center applications was actively pursued.

Today, intermediate drive technology is very well accepted and widely used in underground coal mining. Many mines around the world have incorporated it into their current and future mine plans to increase the efficiency of their overall mining operations.⁶

The tension diagram in Figure 20 shows the simple principal and most significant benefit of intermediate belt conveyor drives. This flat, head driven conveyor has a simple belt tension distribution as shown in black. Although the average belt tension during each cycle is only about 40% of the peak value, all the belting must be sized for the maximum. The large drop in the black line at the head pulley represents the total torque or power required to run the conveyor.

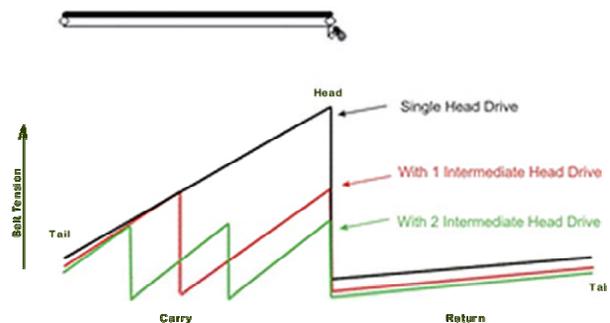


Figure 20

By splitting the power into two locations (red line), the maximum belt tension is reduced by almost 40% while the total power requirement remains virtually the same. A much smaller belt can be used and smaller individual power units can be used. To extend the example further, a second intermediate drive is added (green line) and the peak belt tension drops further.

The tunneling industry was also quick to adopt this technology and even take it to higher levels of complexity and sophistication. But the main need in tunneling was the necessity of using very tight horizontal curves.

By applying intermediate drives (Figure 21) to an application such as the Baumgartner Tunnel as described in Figure 10 above, belt tensions can be controlled in the horizontal curves by strategically placing drives in critical locations thereby allowing the belt to turn small curves.



Figure 21

In Figure 22, the hatched areas in green represent the location of curved structure. The blue line represents carry side belt tensions and the pink line represents return side belt tensions. Notice belt tensions in both the carry and return sides are minimized in the curves, particularly the tightest 750m radius.

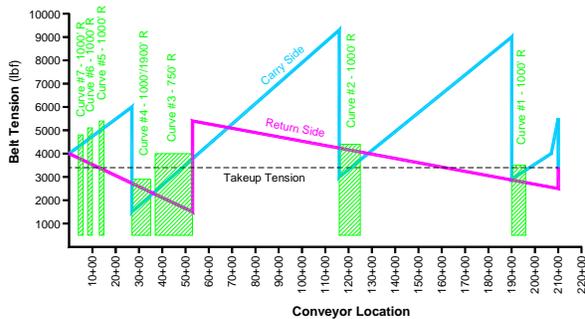


Figure 22

Although aboveground overland conveyors have not used this technology extensively to date, applications are now starting to be developed due to horizontal curve requirements. Figure 23 shows a South American, 8.5km hard rock application which requires an intermediate drive to accommodate the four relatively tight 2000m radii from the midpoint to discharge.

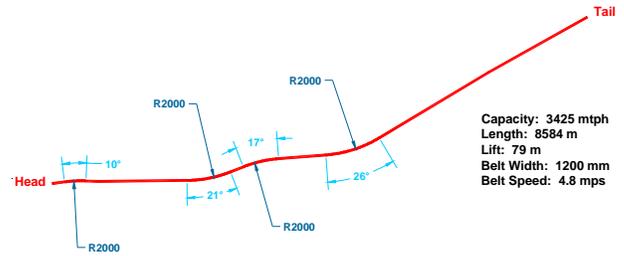


Figure 23- Plan View

Capacity: 3425 mtp
 Length: 8584 m
 Lift: 79 m
 Belt Width: 1200 mm
 Belt Speed: 4.8 mps

Figure 24 shows a comparison of belt tensions in the curved areas with and without distributed power.

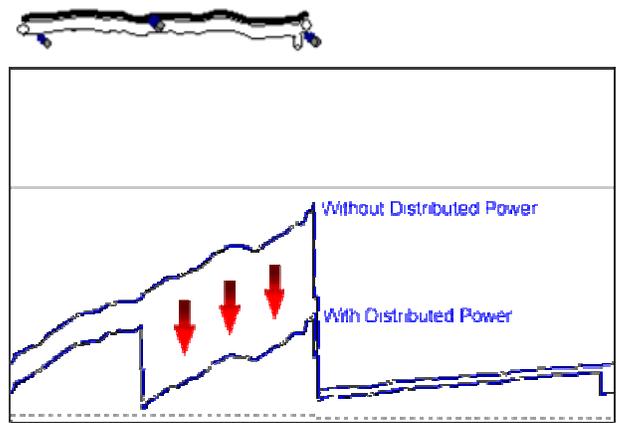


Figure 24- Tension Diagram

The benefit of distributed power is also being used on the MRC Cable Belt. However, since the tension carrying ropes are separate from the load carrying belt, installing intermediate drives is even easier as the material never has to leave the carry belt surface. The tension carrying ropes are separated from the belt long enough to wrap around drive sheaves and the carry belt is set back on the ropes to continue on (Figure 25).

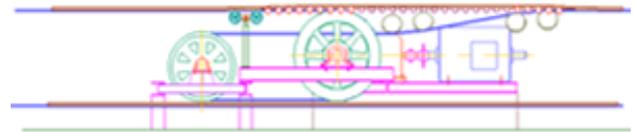


Figure 25

Analysis and Simulation

Many will argue the major reason for our ability to build complex conveyors as described above is advancements in the analysis and simulation tools available to the designer. A component manufacturer can usually test his product to insure it meets the specification; however the system engineer can seldom test the finished system until it is completed on site. Therefore computational methods and tools are absolutely critical to simulate the interactions of various diverse disciplines and components.

Dynamic Starting and Stopping

When performing starting and stopping calculations per CEMA or DIN 22101 (static analysis), it is assumed all masses are accelerated at the same time and rate; in other words the belt is a rigid body (non-elastic). In reality, drive torque transmitted to the belt via the drive pulley creates a stress wave which starts the belt moving gradually as the wave propagates along the belt. Stress variations along the belt (and therefore elastic stretch of the belt) are caused by these longitudinal waves dampened by resistances to motion as described above.⁷

Many publications since 1959 have documented that neglecting belt elasticity in high capacity and/or long length conveyors during stopping and starting can lead to incorrect selection of the belting, drives, take-up, etc. Failure to include transient response to elasticity can result in inaccurate prediction of:

- Maximum belt stresses
- Maximum forces on pulleys
- Minimum belt stresses and material spillage
- Take-up force requirements
- Take-up travel and speed requirements
- Drive slip
- Breakaway torque
- Holdback torque
- Load sharing between multiple drives
- Material stability on an incline

It is, therefore, important a mathematical model of the belt conveyor that takes belt elasticity into account during stopping and starting be considered in these critical, long applications.

A model of the complete conveyor system can be achieved by dividing the conveyor into a series of finite elements. Each element has a mass and rheological spring as illustrated in Figure 26.

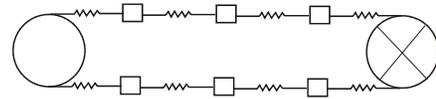


Figure 26

Many methods of analyzing a belt's physical behavior as a rheological spring have been studied and various techniques have been used. An appropriate model needs to address:

1. Elastic modulus of the belt longitudinal tensile member
2. Resistances to motion which are velocity dependent (i.e. idlers)
3. Viscoelastic losses due to rubber-idler indentation
4. Apparent belt modulus changes due to belt sag between idlers

Since the mathematics necessary to solve these dynamic problems are very complex, it is not the goal of this presentation to detail the theoretical basis of dynamic analysis. Rather, the purpose is to stress that as belt lengths increase and as horizontal curves and distributed power becomes more common, the importance of dynamic analysis taking belt elasticity into account is vital to properly develop control algorithms during both stopping and starting.

Using the 8.5 km conveyor in Figure 23 as an example, two simulations of starting were performed to compare control algorithms. With a 2x1000 kW drive installed at the head end, a 2x1000 kW drive at a midpoint carry side location and a 1x1000kW drive at the tail, extreme care must be taken to insure proper coordination of all drives is maintained.

Figure 27 illustrates a 90 second start with very poor coordination and severe oscillations in torque with corresponding oscillations in velocity and belt tensions. The T_1/T_2 slip ratio indicates drive slip could occur. Figure 28 shows the corresponding charts from a relatively good 180 second start coordinated to safely and smoothly accelerate the conveyor.

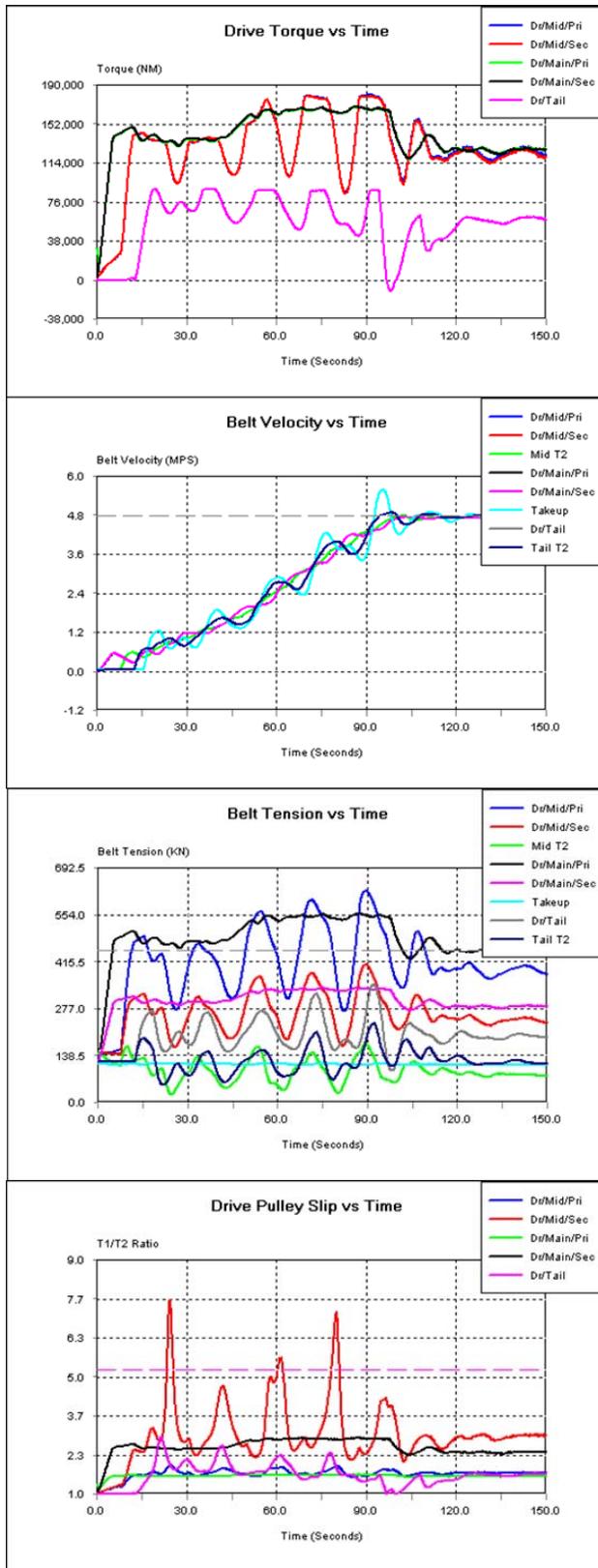


Figure 27- 120 Sec Poor Start

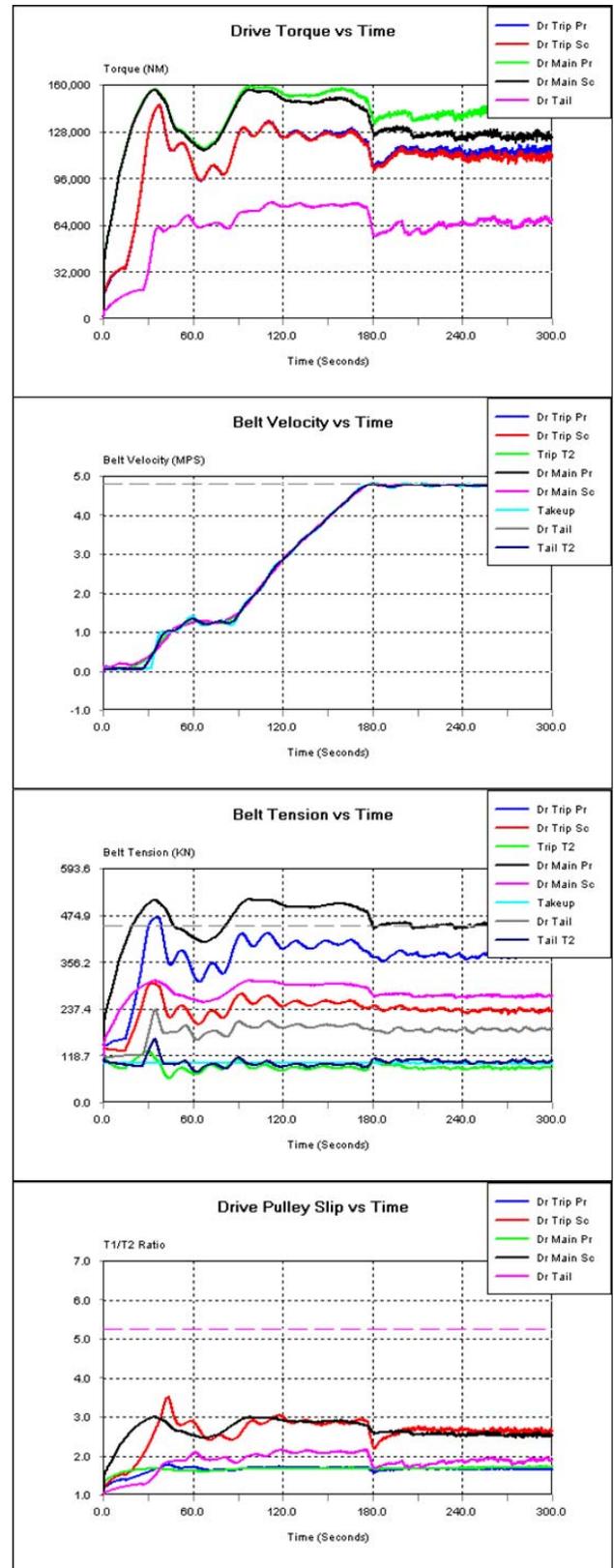


Figure 28- 180 Sec Good Start

Mass Flow at Transfer Points

One of the reasons for using intermediate drives and running single flight conveyors longer and longer is to eliminate transfer points. Many of the most difficult problems associated with belt conveyors center around loading and unloading. The transfer chute is often sited as the highest maintenance area of the conveyor and many significant production risks are centered here.

- Plugging
- Belt and Chute Damage and Abrasion
- Material Degradation
- Dust
- Off Center Loading/Spillage

In the past, no analytical tools have been available to the design engineer so trial-and-error and experience were the only design methods available. Today, numerical simulation methods exist which allow designers to “test” their design prior to fabrication.

Numerical simulation is the discipline of designing a model of an actual physical system, executing the model on a computer, and analyzing the results. Simulation embodies the principle of “learning by doing”. To understand reality and all of its complexity, we build artificial objects in the computer and dynamically watch the interactions.

The Discrete Element Method (DEM) is a family of numerical modeling techniques and equations specifically designed to solve problems in engineering and applied science that exhibit gross discontinuous mechanical behavior such as bulk material flow. It should be noted that problems dominated by discontinuum behavior cannot be simulated with conventional continuum based computer modeling methods such as finite element analysis, finite difference procedures and/or even computational fluid dynamics (CFD).

The DEM explicitly models the dynamic motion and mechanical interactions of each body or particle in the physical problem throughout a simulation and provides a detailed description of the positions, velocities, and forces acting on each body and/or particle at discrete points in time during the analysis.⁸

In the analysis, particles are modeled as shaped bodies. The bodies can interact with each other, with transfer boundary surfaces and with moving rubber conveyor belt surfaces. The contact/impact phenomena between the interacting bodies are modeled with a contact force law which has components defined in the normal and shear directions as well as rotation. The normal contact force component is generated with a linear elastic restoring component and a viscous damping term to simulate the energy loss in a normal collision. The linear elastic

component is modeled with a spring whose coefficient is based upon the normal stiffness of the contact bodies and the normal viscous damper coefficient is defined in terms of an equivalent coefficient of restitution (Figure 29).

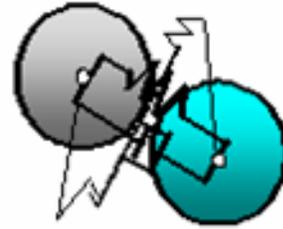


Figure 29

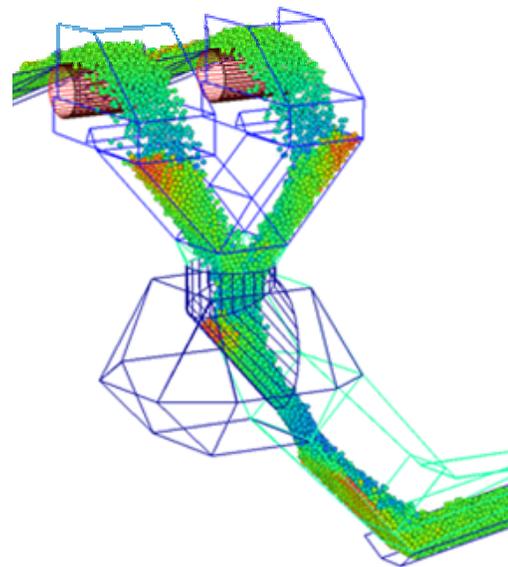


Figure 30

Figure 30 shows particles falling through a transfer chute. The colors of the particles in the visualization represent their velocity. The RED color is zero velocity while BLUE is the highest velocity. Perhaps the greatest benefit that can be derived from the use of these tools is the feeling an experienced engineer can develop by visualizing performance prior to building. From this feel, the designer can arrange the components in order to eliminate unwanted behavior.

Other quantitative data can also be captured including impact and shear forces (wear) on the belt or chute walls.

Future

Bigger Belt Conveyors

This paper referenced Henderson PC2 which is one of the longest single flight conventional conveyors in the world at 16.26 km. But a 19.1 km conveyor is under construction in the USA now, and a 23.5 km flight is being designed in Australia. Other conveyors 30-40 km long are being discussed in other parts of the world.

Belt manufacturers have developed low rolling resistance rubber with claims of 10-15% power savings as methods to quantify indentation have become known. Together with improved installation methods and alignment, significant power efficiencies are possible.

Underground coal mines and tunneling contractors will continue to use the proven concept of distributed power to their best advantage, but now at least two of the longer surface conveyors in development will be installing intermediate drives in 2005.

In Germany, RWE Rheinbraun operates coal conveyors with 30,000 tph capacities and other surface coal mines have plans to soon be approaching these loads. With capacity increases, comes increases in belt speed; again demanding better installation, manufacturing tolerances and understanding of resistances and power.

Each time we go longer, higher, wider or faster, we stretch the limits of our analytical tools to predict system performance. And because each conveyor is unique, the only way we have to predict performance is our numerical analysis and simulation tools. Therefore it is imperative we continue to improve our design tools as our goals get bigger.

Belt Conveyors for Bulk Materials, 6th Ed, CEMA

The Conveyor Equipment Manufacturers Association (CEMA), recognizing many of the trends discussed in this paper, is currently producing the 6th Edition of the worldwide reference manual "Belt Conveyors for Bulk Materials" with longer center conveyors in mind. This is the first major revision of this manual since the 1980's and reflects the need to update design methods for today's demanding applications.

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