Longer Overland Conveyors with Distributed Power

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Abstract

Bulk material transportation requirements are demanding equipment with increasing capacities covering longer distances and more diverse routes. As such, belt conveyors with multiple vertical and horizontal curves traversing many miles have been built and even larger ones are being considered. In order to keep up, significant technological advances have been required in the field of system design, analysis and 'Virtual Prototyping". These technologies have led to the distribution of drive power in multiple locations which has further expanded belt conveyance possibilities. Examples of complex conveying applications along with the numerical tools required to insure reliability and availability will be reviewed.

Introduction

Something happened to straight overland conveyors in the 1990's; their paths no longer needed to be straight. In 1989, a 21 km, 2 flight conveyor with 2 horizontal curves was installed at Channar (Australia). In 1996, a 16 km system with curves was installed at Zisco (Zimbabwe). In 1997, a 14 km flight was installed at El Abra (Chile). In 1998, a 14 km flight was installed at Muja/Collie (Australia). In 1999, a 7 km system transporting material in both directions was installed at BHP DRI (Australia). In 2000, a 14 km system was put in at Ingwe (South Africa) and a 24 km, 3 flight system replaced rail haulage at the Phelps Dodge, Climax Molybdenum, Henderson Mine (Colorado, USA). These are just a few examples of the many groundbreaking applications of curved conveyors.

Prior to the late 1980's, horizontal curves were viewed skeptically as they appeared sporadically around the world. But as you can see, the 1990's was the coming of age for horizontally curved overland conveyors and they are considered mainstream design options today.

This summer, the longest conventional single flight conveyor in the world was commissioned in the USA. It was 19.1 km in length and its route required 11 horizontal curves. In September 2006, a 20 km single flight with 4 horizontal curves is scheduled to be commissioned at Curraugh North (Australia). And new applications of 50 and 100 km are being considered as this is written.

As these applications have gotten longer from the 10-14 km in the 1990's to the 19-20+ km today, distributed drive technology has been brought up from underground in order to facilitate the engineering requirements.

And the distribution of power among several locations on a machine as long as 19 km requires the successful application and integration of several disciplines.

1. Individual Component Engineering
2. Systems Engineering (Simulation)
3. Optimized Interactive Controls
4. Data Acquisition
5. Condition Monitoring
6. Remote Diagnostics

Route Optimization

Figure 1- Tiangin China

Horizontal Curves

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 1 and 2 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.

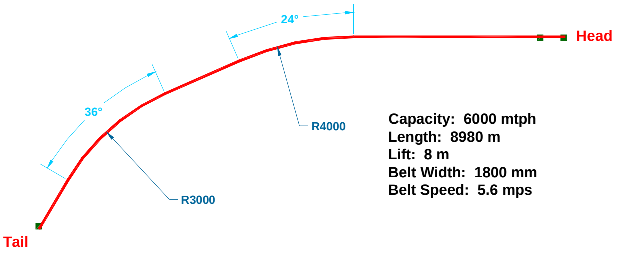


Figure 2- Tiangin China Plan View

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 3) 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. [1]

Figure 3- 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 4 and 5 and has recently received the contract to install the second 8.39 km conveyor.

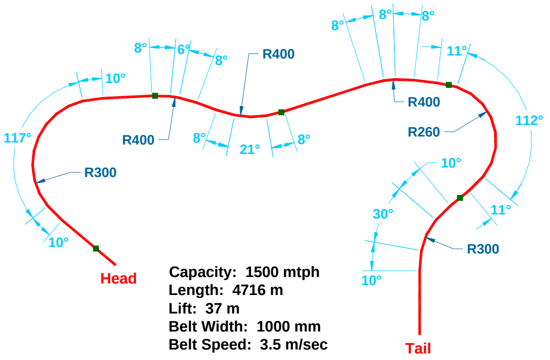


Figure 4- Barcelona Tunnel Plan View

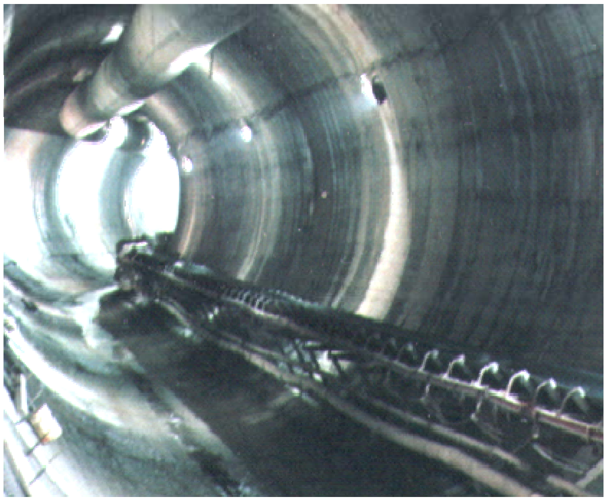


Figure 5- Inside Tunnel

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 6) will be equipped with a 6.1 km conveyor of 600mm wide belting with 4 intermediate drives.

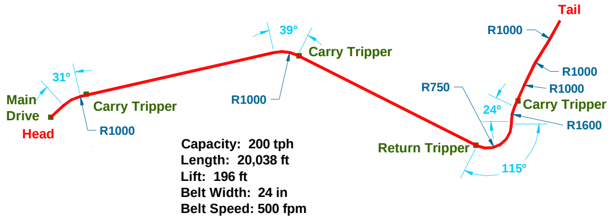


Figure 6- Baumgartner Tunnel Plan View

Distributed Power

One of the most interesting developments in conveyor technology in the recent past has been the distribution of power along the conveyor path. Is 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 (Table 1). Many mines around the world have incorporated it into their current and future mine plans to increase the efficiency of their overall mining operations.[2]

Location	Width (mm)	Length (M)	Capacity (MTPH)	Installed Power (kW)	Inter-mediate Drives
AL	1524	3350	4000	1790	1
CO	1524	2271	4000	5371	3
CO	1800	5377	5000	1940	2
IL	1350	4268	2200	1194	1
KY	1524	3658	3500	2685	3
PA	1524	4410	4000	2237	2
UT	1524	5091	3200	2984	2
WV	1524	6097	3500	3357	4

Table 1- Sample of Intermediate Driven Conveyor in USA Underground Coal Mines

The tension diagram in Figure 7 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.

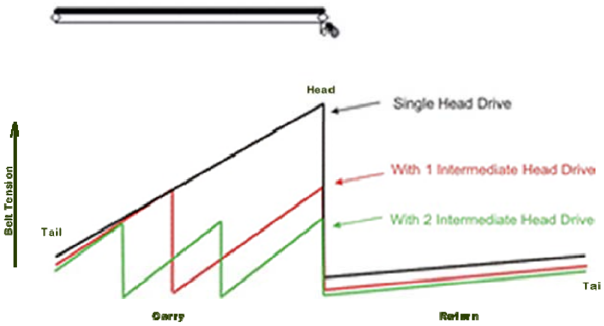


Figure 7

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 (Table 2) 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 8) 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.

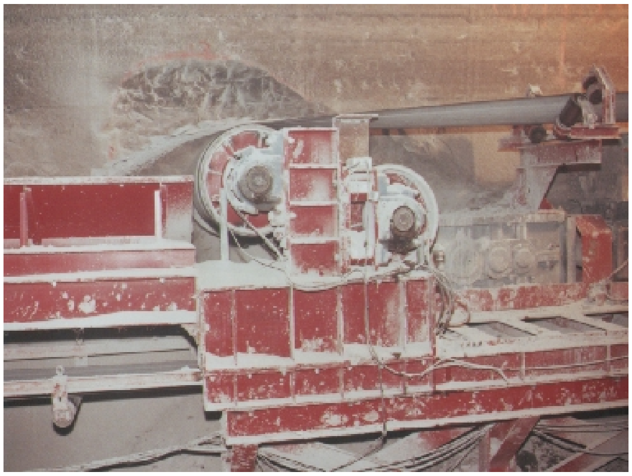


Figure 8

In Figure 9, 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

Project/Location	Width (mm)	Length (M)	Capacity (MTPH)	Horizontal Curves	Minimum Radii	Installed Power (kW)	Intermediate Drives	Installation Completed
DART/USA	750	5395	725	13	300	600	2	1994
TARP/USA	900	13985	1270	17	300	2244	10	1996
Yucca/USA	900	7900	1000	3	300	969	6	1997
CTRL/ UK – P240	800	2 x 4700	800	3	2500	480	1	2002
CTRL/ UK – P250	800	2 x 5300	800	3	2500	640	2	2002
UTE Guadarrama North #3	900	13377	1150	2	7000	1120	3	2003
UTE Guadarrama North #4	900	15000	1150	2	7000	1280	3	2003
Barcelona Metro UTE Linea 9	1000	8,390	1500	6	280	1600	9	2003

Table 2- Sample of Intermediate Driven Tunnel Conveyors

the tightest 750m radius.

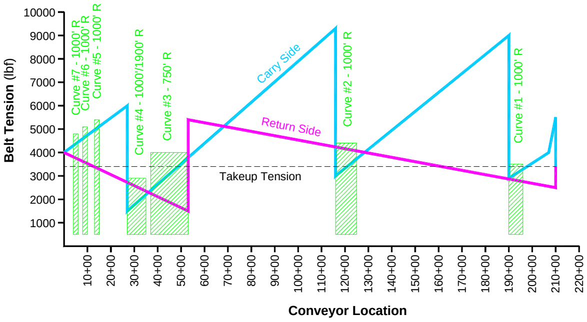


Figure 9

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 10 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.

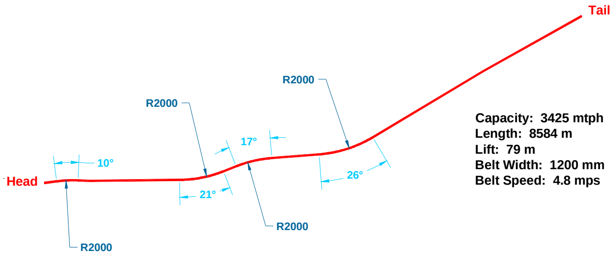


Figure 10- Plan View

Figure 11 shows a comparison of belt tensions in the curved areas with and without distributed power.

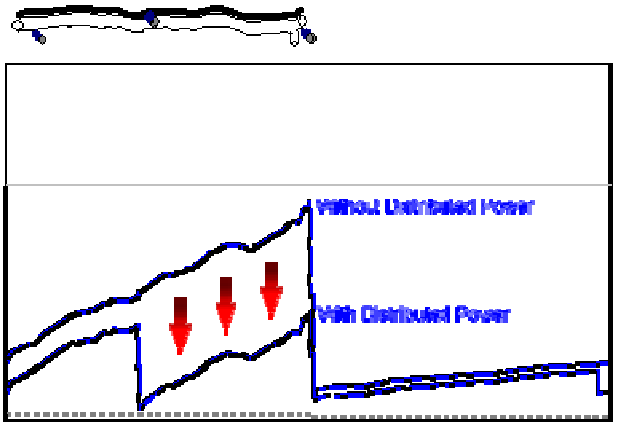


Figure 11- Tension Diagram

Complexity

Although all this technology looks good and exciting, the negative effect of these new, large machines is complexity.

In a recent survey of engineers published by a prominent magazine, 42% identified design and product complexity as the most important issue they face; well ahead of time-to-market pressures (13%), competitive pressure (12%), and cost reduction (11%). And engineering is in the midst of a continuing explosion of complexity. All types of products including cars, computers, and even toasters are more complex than they were ten years ago. But greater complexity brings both new benefits and new problems. For example, new cars can include amazing technology that can tell you where you are and where you should be, but when they break down; they do so in strange new ways that most drivers don’t understand.

Unfortunately, everyone agrees these trends will not be changing any time soon. And all the new wonderful technology in the world is worthless if we cannot produce reliable equipment. Therefore, the implications of this “complexification” require we develop new techniques and strategies for engineering complex systems that deal with these problems.

Design “Testing”

Today’s huge mining machinery share another common characteristic in that final assembly occurs at the mine. These machines are too big to be assembled and “tested” before hand. Although sub-systems and components are tested, the assembled machine (system) is “commissioned” and expected to perform almost immediately.

Overland belt conveyor engineers face an even more difficult task as most every major conveyance systems is totally unique in system design. And today, the many components that must all interact together properly for the conveyor system to function are often manufactured all over the world and only interface during commissioning.

Reliability and Availability

Belt conveyors are used in mining because they are an economical way to move bulk materials over distances up to many miles. But because a conveyor delivers a very small amount of material over long periods of time, it is essential they operate efficiently with maximum availability and minimum downtime. Unlike a truck or train that delivers large loads intermittently, a conveyor must deliver a small, steady stream of material continually. Therefore, reliable and available equipment is absolutely essential in conveyor system design.

System Availability

System availability is calculated by modeling the system as an interconnection of parts in series and parallel.

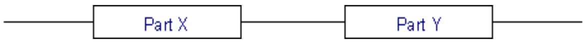
- If failure of a part leads to the combination of parts becoming inoperable, the two parts are considered to be operating in series. This is typical of a conveyor or series of conveyors as a single part failure will stop the whole system and stop throughput.
- If failure of a part leads to another part taking over the operations of the failed part, the two parts are considered to be operating in parallel. This would be typical of a fleet of

Availability in Series

Two parts X and Y are considered to be operating in series if failure of either of the parts results in failure of the combination. The combined system is operational only if both Part X and Part Y are available. From this it follows that the combined availability is a product of the availability of the two parts. The combined availability is shown by the equation below:

$$A = A_x * A_y$$

The implications of the above equation are that the combined availability of two components in series is always lower than the availability of its individual components.



Consider the system in the figure above. Part X and Y are connected in series. The Table 3 shows the availability and downtime for individual components and the series combination considering 6000 hours of operation a year.

Component	Availability	Downtime
X	95%	16 days/year
Y	99%	3 days/year
Combined System	94%	19 days/year

Table 3

From Table 3, it is clear that even though a very high availability Part Y was used, the overall availability of the system was pulled down by the low availability of Part X. This just proves the saying that a chain is as strong as the weakest link. More specifically, a chain is weaker than the weakest link. Therefore designing a highly reliable conveyor system requires the elimination of all weak links.

Failures

Equipment failures over equipment life is sometimes characterized by a bath tub curve (Figure 12). The chance of a hardware failure is high during the initial life of the machine. The failure rate during the rated useful life of the product is fairly low. Once the end of the life is reached, failure rates increase again.

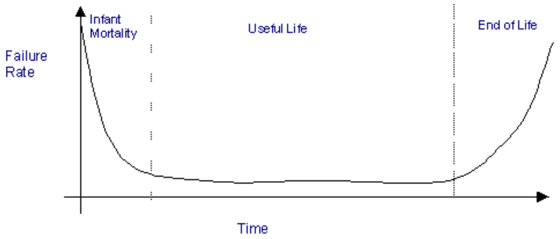


Figure 12

Most owners understand the small rate of failure during the “Useful Life” phase which is why stores of critical spare parts are maintained. And most of us understand that failures increase near the “End of Life” (which usually defines the “End of Life”). But it is much harder for many to understand the reasons for a high “Infant Mortality.” Because these huge machines cost a lot of money, they are expected to perform accordingly. Yet “Infant Mortality” can still be high and frustrating because management is always anxious to see results of their huge investment. These failures can be attributed to the following causes:

1. Manufacturing- This type of failure can be attributed to problems such as poor welding,

improper factory lubrication, contamination, etc. These failures should NOT be present in new components leaving a factory but many do exist as normally only representative components receive complete QA testing and fewer will actually find their way to the manufacturer's lab for destructive life testing. Idlers are good examples, as statistically a few bearings will always fail in the first several hours of operation just due to the shear volume of the product (bearings). Although these types of failures deserve attention and scrutiny, this subject is beyond the scope of this paper.

2. Design- This class of failure takes place due to inherent design flaws in a component or in the system. In a well- designed system this class of failure should make a very small contribution to the total number of failures but it is arguable that design flaws are the most common problems operators face. One reason is system design methods can vary widely from company to company and from engineer to engineer, and defining a "well designed system" is very difficult. And if a component fails, it is not always clear if the component design or the system design is to blame. The complex relationships between the system and the components are the main topic of this paper.

The System vs. Components

The definition of a system is "a set of interrelated components working together toward some common purpose."

1. The properties and behavior of each component of the system ***affects*** the performance of the whole system.
2. The performance of each component of the system ***depends*** on the properties and behavior of the system as a whole.

This concept that component performance ***depends*** on the whole system design provides a troubling concern for all manufacturers as their products can be ***affected*** by conditions outside their control. Are the actual operating conditions their products will be subjected to actually as they are represented by the system designer?

There are many components specialists in rubber, bearings, power, motors, gearing, lubrication, controls, et cetera, that must be knowledgeable in their respective fields for the system to work. But seldom are these individual specialists knowledgeable of the system in which their expertise in used. The field of systems engineering was established and is growing out the need for the system management function in the design of complex machines. The influence of the systems engineer is critical during the early conceptual stages of the design process when the emphasis is on the optimization of the system and not the individual components. At that point, the cost of identifying and correcting unreliability is much less costly than correcting during construction, commissioning, or burn in.

The systems engineer who is responsible for ensuring all the components are working together is critical to the final product. Since a system "test" is not possible, the systems engineer must usually rely on mathematical models to ensure the machine will perform as expected. The quality of the mathematical tools used is directly related to long-term performance and reliability.

These mathematical design tools are now progressing from classical stress, strain analytical tools which are necessary on a micro scale to time-based, simulation tools that are necessary to look at a dynamic system on a macro scale. All of these simulation techniques are sometimes included in a general category called "Virtual Prototyping."

"Virtual Prototyping" Approach to Design

Greater complexity of all components increases the amount of knowledge, information, and communication required to optimize the design. At each step in design development the detailed options multiply and interact, and they all have to be evaluated iteratively against the product performance, quality, and manufacturing cost requirements. If designers and engineers are to cope with these conflicting demands, they need a new approach to the design process, capable of delivering not just higher design and engineering productivity, but a design environment that actually supports and promotes innovation.

Virtual prototyping (or "digital mock-up") has been used for years in the automotive and aerospace industries where it is recognized as the only way to manage the complexity inherent in their products and their engineering business networks. Today, this same approach is being adopted in many aspects of belt conveyance.

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. [3]

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 13.

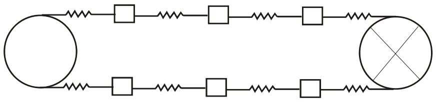


Figure 13

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 10 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 14 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 15 shows the corresponding charts from a relatively good 180 second start coordinated to safely and smoothly accelerate the conveyor.

Control Integration

All the best system simulation and analysis in the world would be worthless if the control logic used in these simulations can not be translated into hardware and software by the control engineers. Huge complex machines of this nature require close interaction between system engineers and control integrators to insure all contingencies are anticipated and proper logic is incorporated.

When large drives miles apart are coupled with an elastic band, they must be capable of working together to fulfill the macro system function but also independently to satisfy the local drive requirements. This requires communication directly between drives but more importantly, communication through the mechanical elastic band itself. Keeping these remote drives working together and not fighting each other requires complex algorithms and precise integration.

As with any complex system, this is most difficult during the critical changes of state; rest to motion (starting) and motion to rest (stopping). And as the machine load varies from start to start, the requirement of the controls will vary from start to start therefore hardwired instructions based on time increments are not the preferred control methods.

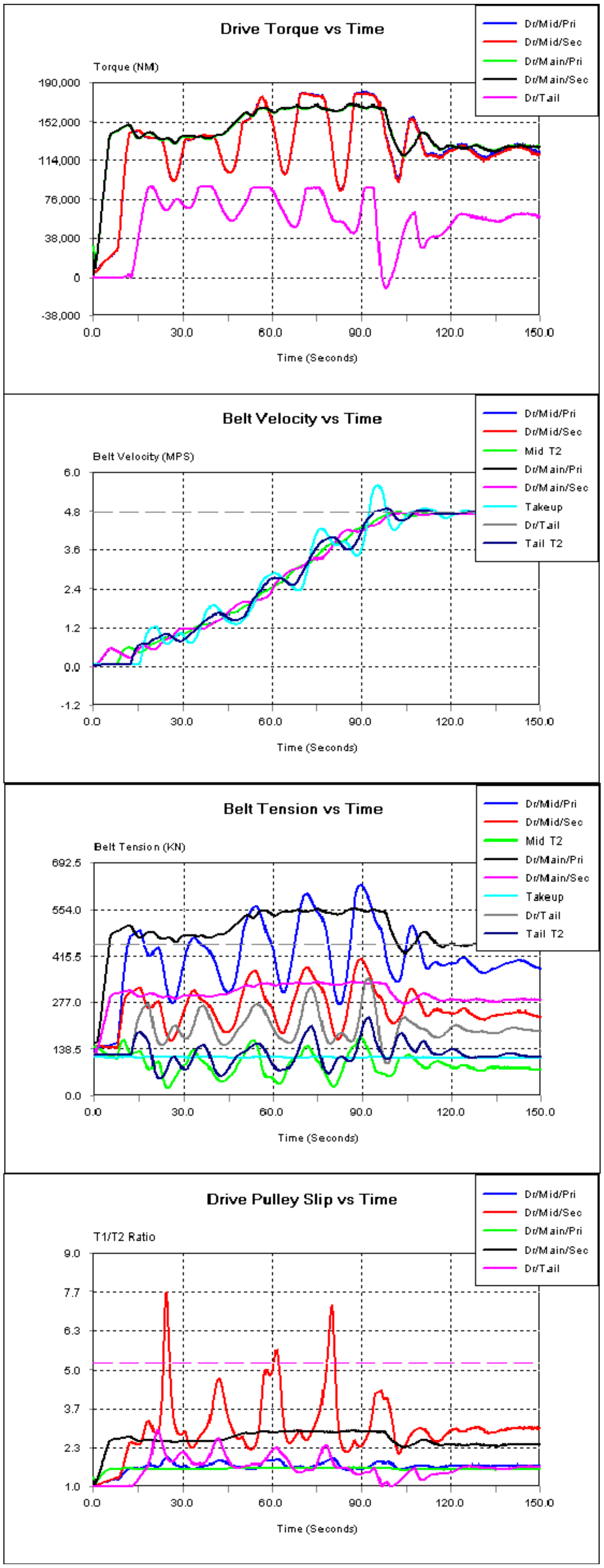


Figure 14- 120 Sec Poor Start

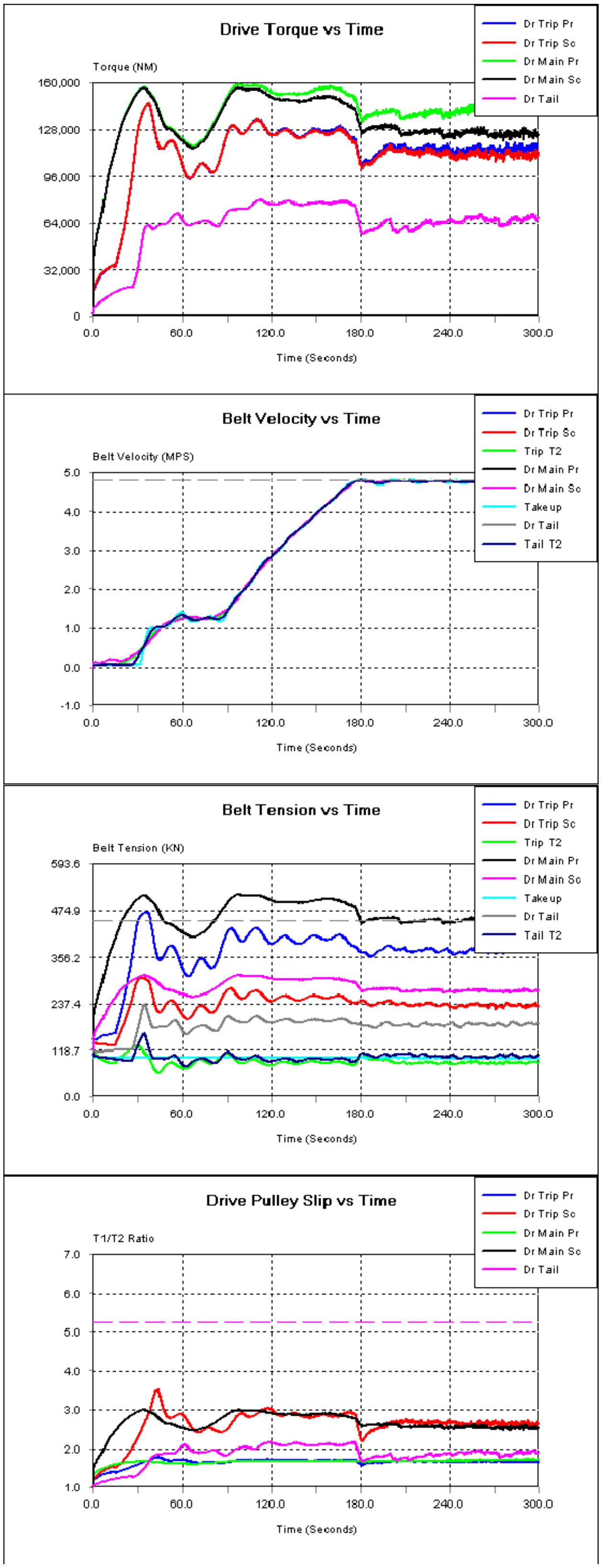


Figure 15- 180 Sec Good Start

Interactive controls require reliable data acquisition as nothing can be controlled reliably unless it can be measured reliably.

And because of the complexity of these systems, condition monitoring and remote diagnostics must be considered important aspects of the system design. Today's systems require expert diagnostics in order to make intelligent decisions when unforeseen problems arise. Because these system experts are often not available at the operation level, it is important to make provisions to communicate performance data to the proper people in a timely manner to get expert analysis in order to make the best decisions.

Conclusions

Belt conveyor systems will continue to get bigger as our clients demand increased production at lower costs. This trend will continue.

Virtual Prototyping

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.

Distributing Power

The logical extension of technology in overland conveyor applications is towards the distribution of power to locations where it will lower the overall system cost and improve reliability. If it lowers capitol cost but increases maintenance and operating costs due to poor availability, the mining industry will find other solutions.

Control and System Engineering Integration

This interaction is becoming increasing necessary and our industries must strive to improve this interaction. The systems engineer must understand what is possible and what is impractical in terms of control techniques. Just because something can be programmed into a computer model, does not mean it can be translated into hardware and software to control a huge machine.

Also the control software engineer must understand the mechanical interactions of all the system components as well as the context of the overall system. Control algorithms which work perfectly in one industry may not be applicable to another. Data acquisition, data archiving and remote diagnostics of both the control alogorithms and the conveyance system must be carefully built into the initial system design in order to commission, fine tune and maintain these complex systems. And control algorithms must be reliable and also simplified to decrease the dependency on experts as much as possible.

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