THE DEVELOPMENT OF AN ST10,000 CONVEYOR BELT

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Abstract

Since the 1900's the global demand and production of minerals and ores has grown at an alarming rate. For example, copper ore production has doubled about every thirty years. In order to match these increasing demands on the mining industry, conveyor belts have increased in both width and strength. If maximum belt strength is plotted against time starting from the first one in 1942, ST10,000 falls in line with 2011. The article describes some of the development work, some of the benefits and some of the challenges of an ST10,000 and discusses safety factors and measures that can be taken to reduce risk to a major belt investment, such as an ST10,000.

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Why develop an ST10,000?

Since man discovered how to extract metals and minerals from the earth his ingenuity has shown no bounds in terms of finding ways to utilize those materials to improve his life and his environment. Simultaneously, as the earth's population has grown, Figure 1, there has been an ever increasing demand for those materials.

To illustrate the rate of growth of this demand, Figure 2 shows the world's production of copper since 1900. The demand has almost doubled every 30 years.

In a valiant attempt to keep up with the ever increasing demand, man has continuously sought and found new ways to improve the methodology and efficiency of extraction and transportation of these desirable materials.

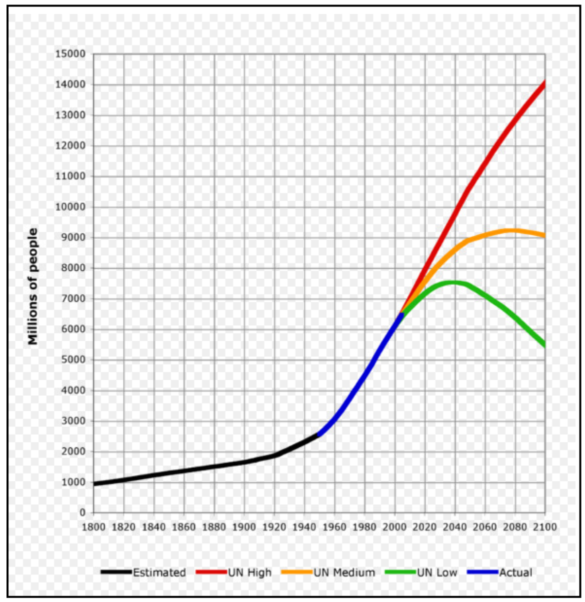


Figure 1. World population growth since 1900 (1)

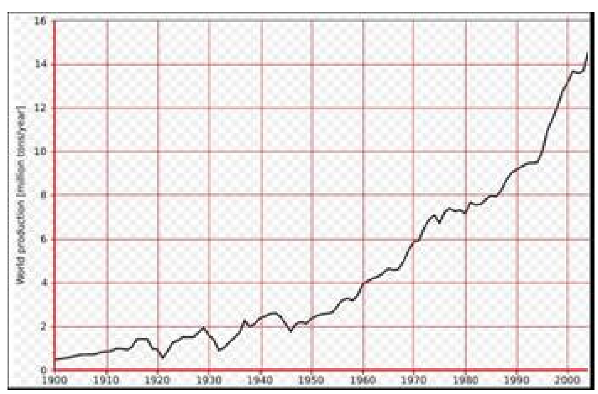


Figure 2. World production of copper since 1900 (2)

Primitive mining and quarrying techniques employed humans and four legged animals such as mules and horses to transport material from the working face of the mine to the material storage area. In some countries these old traditional methods are still in use today. However, for most large mining operations around the world the task of moving the material out of the mine is performed by a variety of bulk material handling methods, most commonly using conveyor belts and/or trucks.

Conveyor belts date back to the late 1800's when conveyor belts made from cotton were used. The first steel cord conveyor belt was made in 1942 in the USA by the Goodyear Tire and Rubber company for the Oliver Mining Company for their Morris iron ore mine. That belt was 2200 ft (671 m) of 30" (762mm) wide Flexsteel 900 PIW (ST1050). These days, almost all bulk handling conveyor belts are rubber covered with either textile or steel cord tension members.

Meeting Demand

In order to meet the increasing production demands, belt capacities, belt lengths and belt lift have seen steady increases. Belt capacities have been increased by

1. Increasing belt widths
2. Increasing belt speeds
3. Using higher capacity idler geometry
4. Employing low rolling resistance rubber
5. Increasing belt strengths

Figures 3, 4 and 5 illustrate the relationship of each of parameters 1 to 3 on belt capacity.

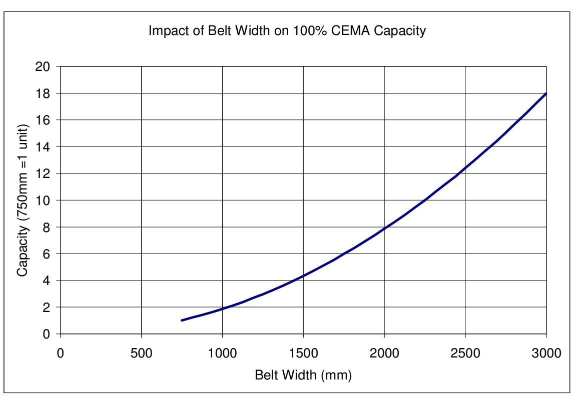


Figure 3, Impact of belt width on belt carrying capacity

Figure 3 shows the effect of increasing belt width on carrying capacity based a fixed speed and 100% CEMA capacity (3). As a reference, the chart uses a baseline of the first steel cord belt made in 1942 as 1 unit of capacity. From the chart it can be seen that the capacity for a 2000 mm wide belt is four times the capacity of a 1000mm wide belt. That is, the capacity is a function of belt width squared. Currently, belts are commonly made up to 3200 mm wide. When selecting wide belts with thick cover rubbers, belt weight becomes an important consideration. Belt handling weight limitations can reduce the possible roll lengths for such belts and may increase the number of splices required for long conveyors.

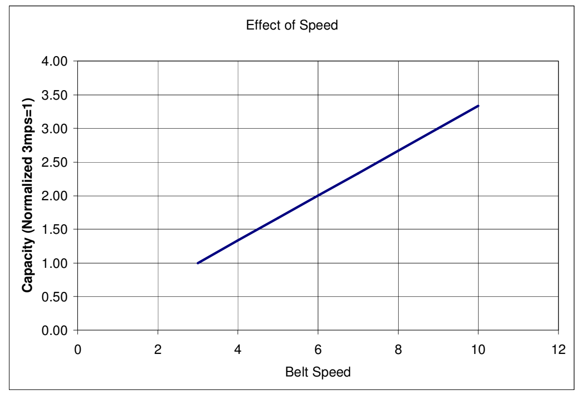


Figure 4, Impact of belt speed on belt carrying capacity

Belt capacity can be increased by increasing belt speed as indicated in Figure 4. This is a linear relationship. Over the past 30 years average belt speeds have increased from less than 600 fpm (3mps) to over 800 fpm (4mps) and higher. There are a number of belts running at 1400 fpm (7mps) and above. Higher belt speeds bring attendant requirements such as longer start and stop times, more elaborate drive controls and possibly higher quality idlers with reduced total indicator run out (TIR) and balance requirements.

Figure 5 shows a simple analysis of the influence of idler angle on the carrying capacity of a belt on a conventional three roll idler for a material with a surcharge angle of 20 deg and a fixed speed. The surcharge angle of a material is the natural angle at which the edge of the material makes to the horizontal on a moving belt. The analysis assumes equal roll lengths and 100% CEMA capacity.

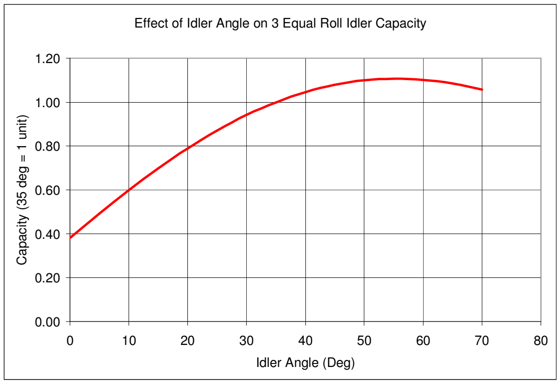


Figure 5, Effect of idler angle on conveyor capacity for a material with a 20 degree surcharge angle

At zero idler angle the capacity equates to a material with a surcharge angle of 20 degrees piled on a flat moving belt. Although the optimum angle appears around 55 degrees, idlers with this angle are seldom used as they would impose severe bending along the idler junctions of the belt which could cause premature failure of the rubber in that area. Most commonly used idler angles for three roll idlers are 35 degrees and 45 degrees. Other geometries with center roll lengths different to the wing roll lengths are possible and are used. However, these are too numerous to detail here.

For a given installed motor power, low rolling resistance rubber (LRR) employed on the pulley cover of an overland conveyor belt can increase a belt's capacity. Traditionally, a belt's pulley cover rubber was made from the same rubber as the top cover. However, studies and measurements of conveyor belt resistance to motion (4), (5), (6) and (7), showed that rubber indentation was the major contributor to belt tension for long, horizontal overland conveyors. This led to the development of specialized low rolling resistant pulley cover rubbers that reduce energy losses from rubber indentation on idler rolls. Currently there is well over 500 km of such low rolling resistance rubbers in service around the world. In addition to using less energy, one of the principle advantages of using low rolling resistance rubber is that it lowers the required belt tension for a given tonnage and installed motor power. Together with other energy efficient system components, this can account for as much as a 25% reduction in belt tension requirement.

For example, the longest single flight overland conveyor in the world (Curragh overland, Queensland, Australia(8)) uses a ST1500 with low rolling resistance pulley cover rubber instead of a ST2500 using conventional pulley cover rubber. In another recent example, a 72" (1829mm) wide ST3500 overland conveyor belt, originally installed with LRR rubber, was commissioned with a capacity of 8800 tph copper ore. When the belt was replaced with a belt with non LRR pulley cover rubber, the conveyor motors could only support 7000 tph capacity.

However, in the case of the ST10,000 where a high lift is involved, the rolling resistance benefit is significantly reduced as the energy required to lift the material becomes dominant.

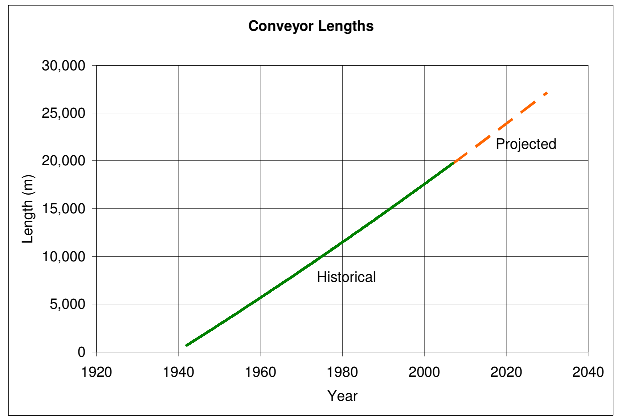


Figure 6, Growth of conveyor lengths in last 70 years

Conveyor lengths have also seen steady increases over the past 70 years, Figure 6. Belt lengths have increased from 670m in 1942 at the Oliver Mining Company's Morris Mine in the USA to 20,000m in 2007 at the Wesfarmers Curragh Pty Limited, overland conveyor at the Curragh North Mine, Queensland, Australia (8). However, conveyor lengths have not yet dictated maximum belt strength. The longest single flight conveyor in the world employs a ST1500. Maximum belt strength is dictated by high lift slope or drift conveyors.

Belt lift and strengths show a similar trend. Notable conveyors are (a) the 1977/2003 1000mm wide ST6000 at BHP Appin coal drift conveyor in Australia, (1600 tph, 520m lift). (b) the 1983, 1300mm wide ST7000 at Selby coal mine slope conveyor in England, (2500tph, 800m lift). (c) The 1986 1400mm wide ST7500 Prosper Haniel coal mine slope belt in Germany carrying material both ways, (1800 tph up/1000 tph down, 783m lift), and (d) the 1998, 1800mm wide ST7800 downhill slope belt at the Los Pelambres copper mine in Chile, (8700 tph, 640m drop). Over the past 70 years we have seen maximum belt strengths exhibit a steady, approximately linear increase, Figure 7. According to this chart, maximum belt strength was forecast to reach 10,000 kN/m by the year 2011

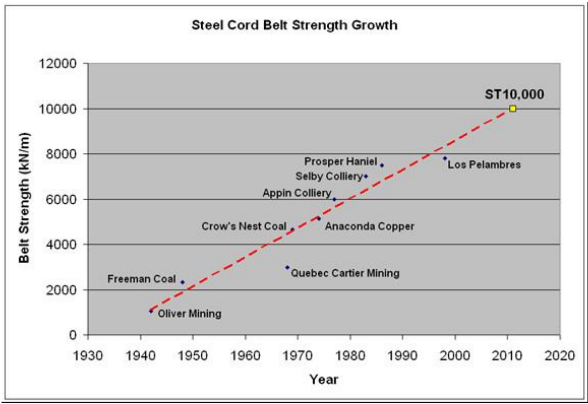


Figure 7, Growth of conveyor strengths in last 70 years

ST10,000 Development

In order to achieve a successful ST10,000 belt design by the year 2011, we have certain requirements to meet. Firstly, the quantity and strength of the steel cords in the belt must achieve at least 10,000 kN/m breaking strength. Secondly, these cords must be designed to meet international standards of rubber penetration to ensure good fatigue life, flexibility and field performance. Thirdly, as there are increasing demands to operate belts at lower safety factors, the belt splice must have a dynamic efficiency (relative reference fatigue strength) of at least 50% as defined in DIN 22110 Part 3.

Cords

Flexible steel cords that are suitable for conveyor belts have been developed over many years by a small number of specialized companies. Typically, these steel cords are made from steel filaments coated with zinc. Zinc is used to provide catalytic protection of the steel in the event that the cord is accidentally exposed to moisture. The zinc is also used to provide excellent bonding to rubber. Conveyor belt cords differ from many common steel cords in that they cannot have residual process oils on them as this would compromise the rubber adhesion to the zinc. This is the primary reason why there are only a few manufacturers worldwide. None are located in the USA. The cords are also designed in such a way to permit rubber to penetrate between the filaments as this helps to protect adjacent filaments from rubbing against one another and fretting which could cause premature failure. Specially developed high carbon steels are used to achieve high specific cord strengths with good dynamic fatigue properties.

As rubber penetration has been found to be critical to successful performance of the steel cord in the conveyor belt, a special test has been developed to measure this. The test is incorporated in an international standard, AS1333 Appendix L. Figure 8 shows a typical test apparatus. According to the standard, a pressure differential of 100 kPa is established across a single cord in a 400 mm long x full thickness sample cut from the belt and the pressure differential is monitored for 60 seconds. After 60 seconds the pressure differential is not permitted to change by more than 5.0 kPa in 60 seconds.

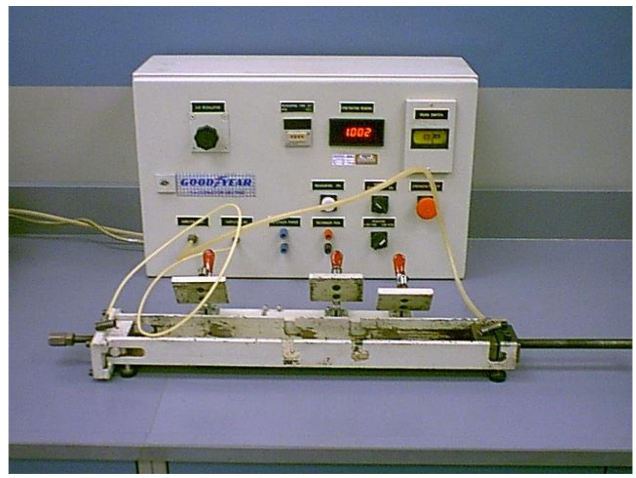


Figure 8, Steel cord air penetration test

For the ST10,000, zinc coated, high carbon steel cords are used that meet the air penetration test described above.

Rubber

Conveyor belts typically use either two or three different types of rubber. The top cover rubber, the insulation rubber and the pulley cover (bottom cover) rubber.

The *top cover rubber* is designed to protect the cords from the transported material. At the load point, where there is significant relative motion between the belt and the material, the rubber must resist abrasion wear. If the material is sharp and/or dense the rubber must resist cutting and gouging damage.

The *insulation rubber* is designed to provide bonding between the cords and the top and bottom cover rubbers. In the splice this rubber transfers the full tension load from the belt on one side of the splice to the belt on the other side of the splice. The quality of this rubber is a major contributor to the dynamic performance of the splice. The dynamic performance of insulation rubber is measured with laboratory tests. Some tests, e.g. AS1333 Appendix K, are performed on a small sample cut out of the belt and others, which also measure splice workmanship, are conducted on a full length splice (DIN 22110 Part 3, discussed later).

The small sample laboratory test is described in AS1333 Appendix K. According to the standard, the test is conducted on a belt sample containing 5 cords. The cords are cut on either end of a 100mm long block in such a way that the center cord extends from one end of the block and the remaining cords from the other end. The cords are gripped in the jaws of a test machine and a cyclic dynamic load is applied to them. The cyclic load is applied with a frequency of between 5 and 10 seconds. The minimum and maximum loads applied to the cords are 3.6% and 36% of the nominal cord pullout load, respectively. The standard specifies that the center cord must not show signs of pulling out after 10,000 load cycles. For the ST10,000 belt, the insulation rubber exceeds 100,000 cycles on this test.

The *bottom cover rubber* has little or no contact with the transported material as its primary function is to ride against the supporting idler rolls. As mentioned above, in certain applications the use of LRR pulley cover rubber can significantly improve a conveyor belt's capacity.

Splice

In addition to the belt cord and rubbers the primary consideration for the belt design is its dynamic splice efficiency. The efficiency of the splice is most important as the splice is required to transmit the total belt load from the cords on one end of the splice to the other. Dynamic splice efficiency is measured with a large scale laboratory test. The test is defined in DIN 22110 Part 3 as the maximum test load that will just achieve 10,000 load cycles. The standard was the result of much research and testing at Hannover University in Germany, (9), and others (10).

Splice Design

As a steel cord's belt strength increases so does the number and/or diameter of steel cords used in the belt. For a fixed belt width, as the number of cords and/or the diameter of cords are increased, the rubber gap between the cords decreases.

In the splice, the cords from one end of the belt are laid between the cords from the other end of the belt. The cords from opposite ends of the belt must have a certain minimum thickness of rubber between them in order to transmit the load from one cord to another without the rubber failing. From laboratory studies, typically the minimum rubber thickness between cords is 2.0 mm to prevent a rapid failure. In practice, larger rubber gaps between adjacent opposing cords reduces the shear stress in the rubber which increases the fatigue life of the rubber and the life of the splice.

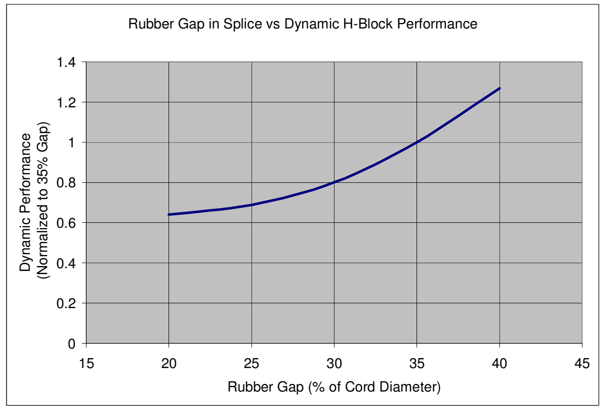


Figure 9, Dynamic performance versus cord to cord gap in a high tension splice based on H-Block test data.

Figure 9 shows how dynamic performance changes with cord to cord rubber gap based on 5-cord H-block test data. Traditionally, a minimum cord to cord gap of 35% of the cord diameter has been used as a design parameter for steel cord belt splices. This is used as the base performance level in Figure 9. In the case of the ST10,000 splice, cord to cord gaps less than 35% are used but the gap is maintained above 2.0mm.

For high strength belts, many large diameter are required. In this case, in order to achieve sufficient rubber between adjacent opposing cords in the splice it is necessary to cut some cords short and organize the cords into an interweaving pattern. The higher the belt strength, the more cords need to be cut. When cords are cut some cords are short and extend only a little way into the splice and some cords are long and extend the full length of the splice.

In order to determine the best pattern in which to cut the cords it is necessary to calculate the rubber shear stresses for each of the possible patterns and select the pattern with (a) the lowest rubber stress and (b) the most uniform cord load distribution. This is best done using specially developed FEA software where rubber and steel properties can be entered. Special consideration has to be included for the rubber physical properties as, unlike steel, rubber behavior is non linear and the non linearity must be defined in the model for each rubber used.

The rubber shear stress between cords in the splice not only varies with the rubber gap between cords but also with its longitudinal position within the splice and with the positions and directional sense of the adjacent cords. Figure 10 shows a section of the FEA analysis used in the development of the ST10,000 splice. The black lines represent the cords. The colored section represents the rubber. The colored scale indicates the shear stress level in the rubber. Blue indicates the highest level of shear stress in the clockwise direction and red the highest level of shear stress in the anticlockwise direction. Green is zero shear stress. Based on many dynamic splice tests, a maximum shear stress of 2.2 MPa is targeted.

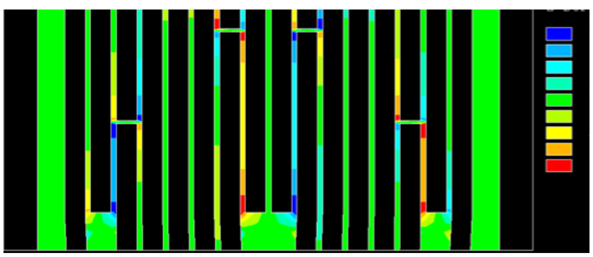


Figure 10. Rubber shear stresses in ST10,000 splice

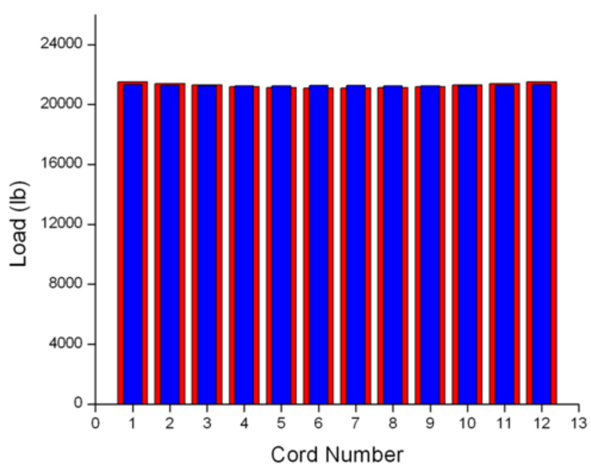


Figure 11. Cord loading in ST10,000 test splice

Figure 11 Shows the FEA calculated load distribution of individual cords in the ST10,000 splice test loop. The red columns represent the cord loading of the individual cords entering from one end of the splice and the blue columns represent the cord loadings for the corresponding cords entering from the other end of the splice. The chart shows that the splice pattern achieves a very uniform load distribution which is a primary goal for any splice design.

Splice Validation

In order to validate the dynamic performance of the ST10,000 splice, the splice was tested on the 2-Pulley Dynamic Splice Tester in Marysville, Ohio at Veyance Technologies Conveyor Belt Technical Center, Figure 12.

Figure 12. 2-Pulley Dynamic Splice test machine

In the 2-pulley dynamic splice test, the maximum test load is cycled every 50 seconds according to DIN 22110 Part 3. The load is applied in a saw tooth manner as shown in Figure 13. The cycle is designed to roughly simulate the tension load applied to the belt in the field. That is, the load is slowly increased at the beginning of the cycle, simulating load build-up from the tail to the head, then drops quickly, simulating the tension drop on the drive pulley.

Figure 13. DIN 22110 Part 3 test load cycle

Other test parameters used for the ST10,000 on this test are

-30.0m long loop x 279mm wide loop
-50 second load cycle (42 up, 8 down)
-Cyclic load 6.6% to 40% - 60% of belt break
-Target life is 10,000 load cycles (5.8 days)

Per DIN 22110 Part 3, test results are shown in the form of a Wöhlers Curve, Figure 14.

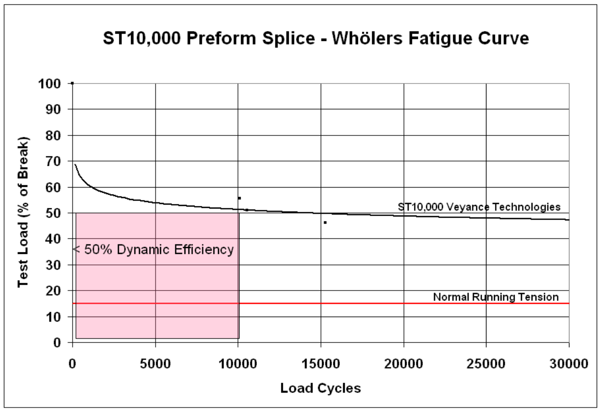
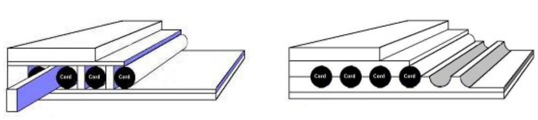


Figure 14. 2-Pulley Dynamic Splice Test results

Per DIN 22110 Part 3, the relative reference splice fatigue strength (often referred to as the dynamic splice strength) is defined as the load at which the splice would achieve 10,000 load cycles on the test. In the case of the ST10,000 the splice exceeds 50% at 10,000 load cycles.

Successful dynamic performance of high tension splices depends on good cord alignment and uniform spacing in addition to high performing insulation rubber. In order to consistently achieve good cord alignment and spacing, The ST10,000 splice employs Splice Preforms®. Essentially, these are pre-molded rubber panels with ready made grooves at the correct cord pitch. The wide panels maintain cord straightness due to their high lateral bending stiffness. Preforms® effectively eliminate the difficulties associated with cord alignment and spacing commonly experienced by splicers using conventional methods. In the conventional method, long, thin rectangular rubber noodles are used between cords. For large diameter cords (> 10.0 mm) five noodles are used as small noodles are used to fill in the triangular voids formed between the circle of the cord and the square formed around it by the rectangular noodles.



Conventional Noodles Preforms®

Figure 15. Schematic of a conventional and Preforms® splice

Figure 15 illustrates and compares the assembly of a conventional splice using rubber noodles (left) and one using splice Preforms® (right). Figure 16 shows a rubber splice Preforms®.

Figure 16. Rubber splice Preform matrix with cord

Good cord straightness and spacing uniformity provide measurable performance benefits. In a static break test conducted by an independent laboratory in S. Africa a 1200mm ST1250 Preform splice exceeded the nominal break strength of the belt. This was 10% better than the best conventional splice made on the same belt. Similarly, on 2-pulley dynamic splice tests conducted on a ST4500 splice on Veyance's 2-pulley Dynamic Splice Test, Figure 12, dynamic splice life of a splice made with Preforms® was increased by 30% compared to a conventionally made splice using noodles.

Benefits and Challenges of the ST10,000

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The ST10,000 offers a number of benefits. The primary one, as discussed above, is its application to high lift conveyors. To put this in perspective, let's look at how it could be applied to an existing well known application. Currently, one of the highest rated conveyor belt operations is at Los Pelambres Copper Mine in Chile. This downhill system uses three conveyors, two ST7800 and one ST4000 belt to complete the drop from the mine to the coast. Using an ST10,000, the same drop can be achieved with only two conveyors, one ST10,000 and one ST7800, Figure 15. This arrangement eliminates one transfer station. In doing so it reduces the risk associated with every additional component required for a transfer station. It reduces belt wear, the potential for belt damage, and the need for maintenance manpower for the transfer station. In this particular application, where much of the belt operates inside tunnels, maintenance access is difficult for interim transfer points.

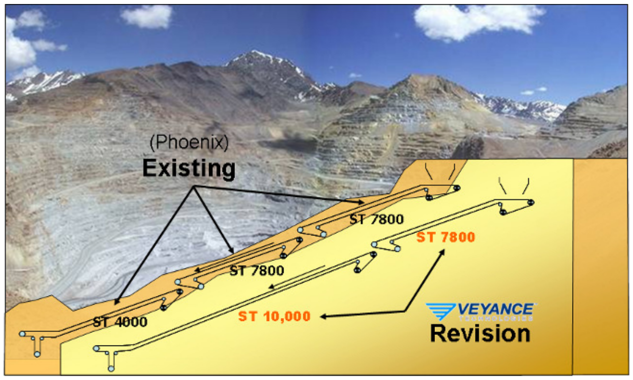

Figure 15. Applying an ST10,000 at Los Pelambres

Potentially, an ST10,000 would be capable of a 40 km single flight although economics may favor a lower strength belt and booster drives.

Although the development of the ST10,000 is a natural step in the advancement of conveyor belts it brings challenges to other conveyor components. For example, the tremendous torque required to drive an ST10,000 exceeds current gearbox technology. Fortunately, electric motor manufacturers' have anticipated this development and have designed gearless motors to work with an ST10,000 belt. The gearless motor development is based on proven, existing technology that has successfully been in use for cranes for several years.

ST10,000 Operating Tension

Although the nominal minimum static breaking strength of the ST10,000 is 10,000 kN/m, its operating tension depends on the safety factor chosen for its application. For each application the chosen safety factor is a risk decision that depends on many factors. Higher safety factors increase splice and cord fatigue life and increase the margin of safety that can accommodate accidental damage. Lower safety factors reduce splice life, cord fatigue life and the margin of safety following accidental damage. If a belt is a lifeline belt, a belt failure would stop mine production until such time as the belt is repaired or replaced. In large mines, this can amount to millions of dollars lost production per day.

Practical experience suggests that serious belt issues most commonly occur after the belt has been weakened by accidental damage that is not repaired quickly. In practice, high lift high tension conveyor belts have commonly been designed to run around safety factors of 6:1. Examples are the ST7800 belts at Los Pelambres (8500 kN/m actual break, 1420 kN/m operating) and the Prosper Haniel ST7500 (8200 kN/m actual break, 1370 kN/m operating). The ST6400 Drummond Coal slope belt in Alabama, operates at 5.7:1 safety factor (6400 kN/m actual break, 1120 kN/m operating). These belts have all exceeded 10 years service life.

The appropriate safety factor for a given application should be determined from a risk analysis that would include considerations of how critical the belt is to the operation, the probability of belt damage from impact and/or tramp material, how good the belt maintenance will be, the impact of the stopping and starting times, the effect of the transitions and vertical curves on belt tensions and the likelihood of the belt's capacity being increased in the future. Beyond increasing the basic breaking strength of the belt, a belt's capacity to operate at low safety factors can be enhanced by increasing the dynamic splice efficiency, by taking measures to avoid accidental damage from high impact or tramp material and by constantly monitoring the belt's condition in order to identify cord damage before it deteriorates into a catastrophic event.

Measures that can be taken to avoid impact damage and/or tramp material damage include careful chute design that reduces material impact on the belt and the use of an electromagnet before or after the chute to remove tramp metal objects.

Measures that can be taken to constantly monitor the condition of the belt's cords exists in the form of rapidly developing cord scanning technology

Cord Monitoring Systems

Cord scanning systems have been around for many years. Originally developed in Australia, the technology has developed rapidly in the past few years as it has been integrated with imaging software. What used to be a few lines on a graph indicating the cords' magnetic strength signal which required specialist knowledge to interpret is now a 2-D colored map of the entire belt that is intuitively understood by the user. The new software, which is available real-time on a website, automatically analyzes and interprets the data, prioritizes damage sites for repair, e-mails alarms to critical mine personnel and issues a complete report on demand.

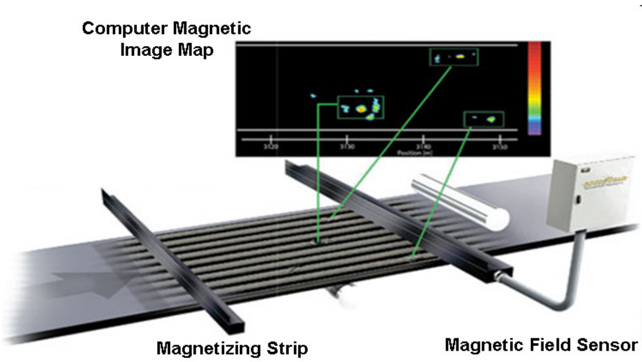

Figure 17. Cord Guard® real-time cord monitoring

Recent enhancements of this technology include embedded panels in the belt which, when cut through by an object that has penetrated the belt, will identify if the belt has been accidentally ripped. In this event, the software identifies the change in the magnetic image of the panel and will automatically shut the belt down before the entire belt is slit in two.

Summary

The ST10,000 has been developed to meet an exponentially growing world demand for minerals that has driven up average mine outputs. Increasing belt strength is one way to achieve higher conveyor belt capacities in addition to increasing belt widths, belt speeds, optimizing idler geometries and using low rolling resistance rubber. The historical trend of belt strengths predicts the ST10,000 for the year 2011. Developing the ST10,000 requires careful selection of the cord and rubber. The cord construction is designed to allow good rubber penetration to help flexibility, fatigue life and corrosion resistance. Top cover rubber is designed for good abrasion and cut and gouge resistance. Insulation rubber is designed for good cord and rubber adhesion and for good dynamic fatigue performance in the splice. Pulley cover rubber can benefit in certain applications from the use of low rolling resistance rubber which permits a higher belt capacity for a given belt strength. Validation of the ST10,000 splice is achieved using a 2-pulley dynamic laboratory test which was originally developed by Hannover University now incorporated in DIN 22110 Part 3. The ST10,000 achieved a 50% relative reference fatigue strength or dynamic splice strength. Cord alignment and spacing in the splice was optimized by using splice Preforms®. which are wide insulation gum panels with grooves pre-molded at the cord diameter and correct spacing. The ST10,000 can eliminate a transfer station, its attendant risks, belt wear and maintenance manning. The operating tension of the ST10,000 depends on the safety factor chosen for its application. Safety factors are chosen by the conveyor engineer after a risk analysis which includes considerations of the impact of a belt failure on production, start and stop times, curve radii and transition lengths, the probability of belt damage from impact and/or tramp material, how good the belt maintenance will be and the likelihood of the belt's capacity being increased in the future. Historically, high tension high lift belts with safety factors around 6:1 have run over 10 years. The most common cause of belt failure occurs after accidental belt/cord damage that is not identified and corrected quickly. In these cases, cord damage reduces belt strength and reduces the operating safety factor. New cord monitoring technology provides real time imaging of cord condition and automatically alerts mine personnel of a dangerous condition. The technology effectively reduces the risk associated with damage induced reduced safety factors by advising mine personnel in time to take corrective action before further deterioration occurs.

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