TRENDS IN THE APPLICATION OF TROUGHED CONVEYOR BELTS

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1. SUMMARY

The scope and practicality of conventional conveyor belts for moving bulk materials has become more significant in the past few years. Recent research developments have led to long and curved overland belts, long drift belts, tube conveyors and wide belt systems. This paper addresses new areas of development which will play an important role in the development of faster conveyor belts, belts with lower tensile ratings and environmentally acceptable designs. The necessity for conveyor belt monitoring is discussed as a means of improving system reliability.

2. Introduction

The conventionally troughed conveyor belt has been used extensively in the bulk materials handling industry for over forty years. The development of steel-cable reinforced conveyor belts has given belt system designers the flexibility to design long and high lift applications for these belts. Industry now operates belts over many kilometres with tensions of up to 1 MN. However, with the use of existing materials and current practice there is a limit to the further application of conventional systems.

Current practice in belt conveyor system design (in Australia) dates back twenty years and closely follows the original developments made in Europe. A gradual scaling-up of belt systems has occurred in the past decade due to the need for higher tonnage applications and longer distances of continuous conveying. The steel-cable-reinforced conveyor belt has fulfilled many of the requirements; however, large safety factors are employed to guarantee reliability. Large design safety margins are very expensive and are not warranted when by correct design it is possible to reduce existing safety margins from 10:1 to as low as 3:1 [1].

In order to achieve these reductions new design philosophies are needed that result in reliable systems at a lower installed cost. The conveyor industry has not seriously attempted to improve design concepts to take into account dynamic effects in the most expensive item of the system - the belt. This paper outlines the current philosophy in improving belt-system design and associated handling technology. Through the application of engineering dynamics and economic analysis to the complete belt system it is possible to develop cost effective designs [21. The areas of research include new starting and stopping methods, narrow high-speed belts with speeds in excess of three times that in present use, material behaviour, environmental interaction and cost effective design. The economic advantage of optimal mechanical design appear to be significant.

3. Reduction in Belt Safety Factor

The safety factor (SF) employed in steel-cord belt systems is of the order of 7:1, and with splices the total SF is usually 10:1. The origin of these figures is not certain [3], and in a recent paper presented at the Australian conference "Belt conveying of bulk solids" held in Nov, 1982, it was suggested the figure of 6.67:1 was in
common use but it may be possible to reduce this value to 4.5:1. No argument to support this view has ever been forwarded in the design literature.

At the same conference, evidence was presented based on calculable starting and stopping characteristics that would permit the use of belt SF to as low as 3:1 [1]. This subject will be dealt with in another paper at this conference of Beltcon 2.

A reduction in the operating SF on steel-cord belting has, of course, a significant cost advantage. The cost of the belting itself decreases as SF decreases, and it must be remembered that the belt forms a significant component of the system cost. In addition, the belt weight decreases with lighter strength belts. This single factor is important for two reasons. Firstly, the power to drive the belt is less for lighter belts and this reduces the size of the motor and associated drive systems. Secondly, the natural frequency of the belt in the unsupported return span increases as its mass decreases and so it is possible with correct design to eliminate the onset of transverse flexural vibration [4]. This dynamic effect will be discussed further.

There is therefore every incentive to reduce belt SF for both technical and economic reasons. Some authors believe that 13 mm diameter cables may be the largest that will be used in conventional belting and that SR8OOO (8000 kN/m width) is the highest tensile rating these particular belts will achieve [31. Research into belt splicing at CSIRO suggests these figures are questionable. Large diameter cables present particular splicing problems, not only in the type of splice construction (layout) but also in guaranteeing the low values of elastomer shear strain necessary to prevent adhesion failure in the splice [5].

Furthermore, belts with very large diameter cords have high values of bending stiffness (EI ~ 100 Nm^2) and require large diameter (- 3m) drive drums, snub pulleys and tail pulleys. Transitions need to be long [6]. In total, these systems require space, and costly drive units to move the heavy belt.

A fundamental point which should not be overlooked is the meaning of the SR rating on steel cord belting. A belt with an SR8000 rating can operate in a system with T_1 tensions of 1.2 MN. However, using a SF of 3.3:1 with a designed acceleration time of 55 s, the belt strength can be reduced to an SR4000, in which the cords are nominally 8-9 mm. The belt mass for SR8OOO and SR4000 is 88 kg/m and 48 kg/m and the costs are typically $330/m and $220/m respectively.

4. Belting Trends
4.1 New belt materials

In the previous discussion, the belt weight was shown to significantly depend on the weight of materials used in the belt construction. New materials such as aramid-Polyamid (kevlar) and polyester- polyamid have tensile strengths comparable to steel ($E \sim 2 \times 10^5$ MPa) with a much lower mass. These light-weight high-strength synthetics are finding their way into the belting industry. The present cost of kevlar belting is approximately 20% higher than the equivalent strength steel-cord belting. Kevlar belting is being manufactured under licence to Du Pont in Germany by 5 companies (Vinyplast - DbPb 1200 - 4000 kN/m width).

Figure 1(a) illustrates a belt constructed with kevlar cords. This belt is already being manufactured in Europe. Figure 1(a) also illustrates the use of amorphous (glassy) metals to reinforce elastomers. These materials are very strong since there are no crystalline structures from which crack-tips could propagate. of course, carbon fibres may also have applications in belt design as an impact resisting layer. Figure 1(b) shows the potential for ceramic inserts to replace idler bearings.

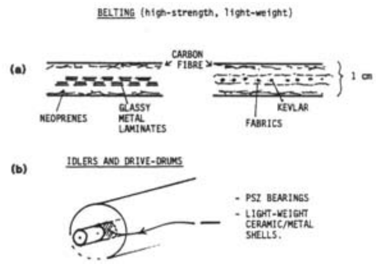

Figure 1(a) Proposed belt designs using new materials.
Figure 1(b) Application of ceramics to idler design.

There are problems associated with these new materials. Flexibility in the longitudinal direction must be maintained. Kevlars are particularly weak in compression and high curvatures such as experienced on small drums would lead to failure of the fibre cord. Adhesion to elastomers may require several pre-coatings of bonding compound. This particularly applies to glassy metals, The cost of these new materials is nearly competitive with steel of the equivalent amount. However, fabric reinforced belting using Kuralon/nylon and polyester/nylon fabrics will continue to have a place in the mining industries of the future.

Fabric belt technology is well known and with the application of soft-start drives [4] resulting in a lowering of SF values, the fabric belt becomes very competitive with steel-cord belts. Steel- cord belts will in future have smaller diameter cords (< 8 m) and will operate at SF ~ 3:1. New methods for rip-prevention will be employed to a greater extent, particularly the use of a fabric impact resisting ply layer and transverse cords to discourage rip propagation.

3.2 Rubber covers

A point not to be overlooked with the application of high strength steel cord conveyor belts is the life-time of rubber compounding used in the belt covers. Additives employed to give fire retarding and antistatic properties to the rubber (FRAS) result in less flexible rubber covers. It is not uncommon to find belting with cover hardnesses of 700 (Durometer) at the time of manufacture. Recently in Australia, belting with a cover hardness of 75° was manufactured. Research has shown that when a cover flexes and ages it work hardens, and when the hardness reaches 78° - 80° the covers will crack [13]. It appears that the rate of hardening is of the order of 1½°/annum using field measurements on working belts. At this rate, cover cracks would appear after 2 years if the cover's initial hardness was 75°. in all cases, the bonded layer in the belt shows no sign of hardening and remains ~ 65° - 68°. This is due to the fact that FRAS additives are not present.

Cover cracks can extend into the bonded layer resulting in spontaneous rips along the belt. At this stage, major failure has occurred. Transverse crazing also occurs on the covers of hard belts and is caused by bending around pulleys. Another reason for discussing this subject is that it has important implications to splicing. The splice in a steel-cord belt relies on adhesion of the bonded rubber to the cords, and the splice strength is the result of the elastomer in shear between adjacent cables. Adhesion failure would certainly occur if FRAS compounds were employed in the bonded layer, and the splice would pull apart. It is therefore vital that safety oriented groups do not try to enforce the use of totally FRAS belting.

4. Increased Belt Speed

Work on this subject has progressed on two fronts. The application of an economic model for belts at the University of Newcastle [4] has led to the conclusion that belts should operate as fast as possible and the belts should be narrow.

Independent research at the CSIRO [8] has shown from a technical point of view that a dynamically stable design is best achieved with narrow (less than 1 m) high speed belts [4]. The basis of the technical design requirements is that a belt can be analysed as a stiff plate. This leads to a 4th-order partial differential equation [4] which has solutions for the plate depending on the boundary conditions of the edges. Figure 2 shows some typical modes of sections for flat and V-belts.

The frequency equations for these various plate configurations are too complex to include in this paper. The flexural frequencies depend on the plate width, length, flexural rigidity in all directions, the belt mass, the belt tension and, in the case of free edges, the Poisson's ratio.

The aim is to design idler separation, belt tension, belt mass and stiffness so that the fundamental bending mode will not be excited by the rotational idler frequency [9].

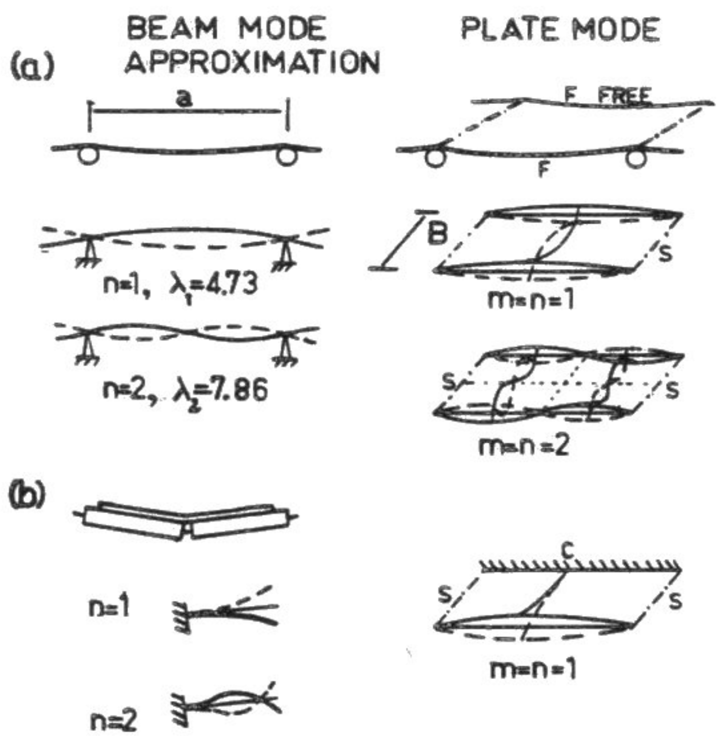

Figure 2. Some of the modal shapes for flat belts and V-return belts.

The model suggests that the belts will need to be lighter in weight, and narrower in width. With experimental designs to date the belt could move at speeds of up to 15 m/s. Some effects used to be verified in practice. For example, the behaviour of a sagging belt on the return span at high belt speed needs to be investigated, taking into account the belt bending stiffness and its effect on hysteresis losses at the idler. The other area of interest is the behaviour of the material on the belt at high speed. The environmental aspect of dust generation could be significant. Other obvious areas of concern are belt wear at high speed, although it is felt that the loading velocity will play an important role in belt wear.

Roberts et al [7] have shown that the wear on a belt cover, termed the wear factor $F_w$is :

$F_w=½.Q_m.(V_b-V_m)^2.Nm/s$

Where Q_m is the mass-flow rate, $(V_b - V_m)$ is the relative velocity between the belt and the material being loaded. The wear is directly proportional to the velocity difference squared and so for fast belts some means of accelerating the material onto the funning belt is needed, so as to minimise $(V_b- V_m)$ and thus minimise F_w. Unloading of the material requires deceleration and transfer.

Fast belts will not be short belts, unless $(V_b - V_m)2$ is close to 0, since high-cycle belts would wear rapidly if the above condition was relaxed.

Not only will fast belts wear due to abrasion but any impact damage leading to rips would be disastrous. It is therefore important that adequate monitoring be installed to monitor rates of wear and detect rip-inducing bodies before they reach the fast belt.

5. Conveyor belt monitoring

During the past two years, an important development has occurred that will have long term impact on the conveyor belt industry. That is the development of the conveyor belt monitor (CBM) [11]. The original research conducted at CSIRO by the author has been successfully Commercialised by the company Conveyor Belt Monitoring. This company perfected the practical use of the system for monitoring steel-cord belting [12].

This new technology has implications for both belt users and manufacturers. Not only is the monitor being employed to prove the quality of manufacture in the factory, it is being used in the field to test installed systems. Older system are being monitored for cover wear, corrosion and splice makeup. Newly installed systems are being monitored to provide base or reference data from which deviations in the future can be compared. Thus, the rate of deterioration of a given belt parameter can be measured. The technology is gaining acceptance in South Africa and Germany.

The monitor is non-destructive and generates belt data without interrupting production by operating on the return span of the belt.

Figure 3(a) illustrates the position of the CBM in relation to the belt, and figure 3(b) shows a chart record of corrosion and splices detected in a belt section.

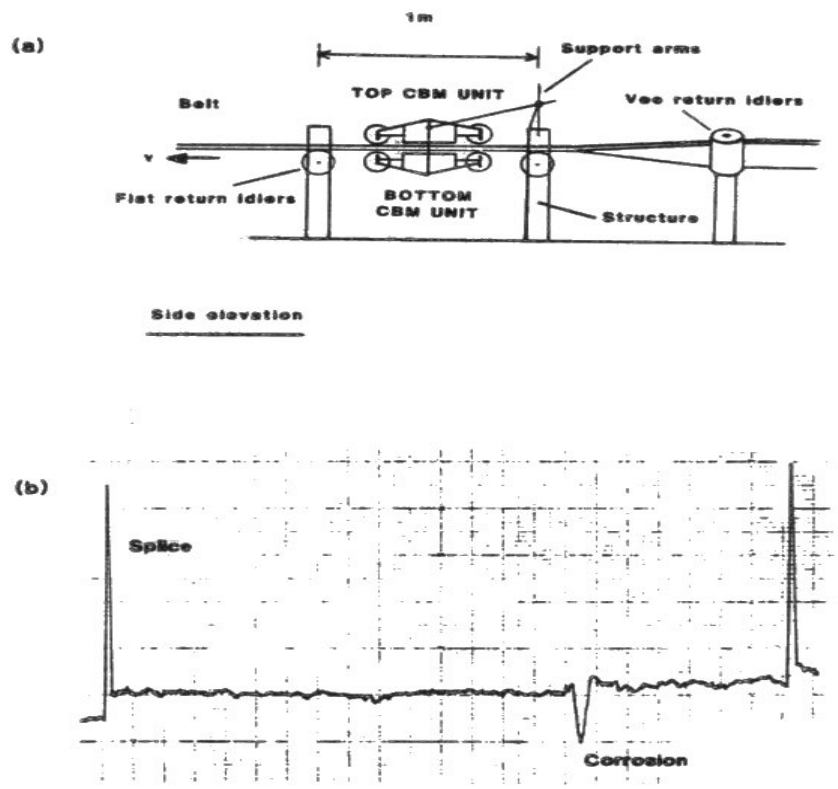

Fig. 3(a) Schematics of a CBM (b) Typical steel mass SCAN showing corrosion and splices.

Perhaps a more important aspect of this new activity is the development of interpretative skills and troubleshooting capacity in related areas such as design improvement. It is not uncommon now to find CBM professionals expanding their energies into areas of design consulting encompassing feeders to reduce wear, placement of idlers to stop belt flap, calculation of peak stresses in belts and splice analysis [5].

In general, the monitoring of large and small belt systems is rapidly becoming an industry requirement that will serve to improve reliability, and provide much needed knowledge to allow planned shutdowns for maintenance in place of costly 'crash' or breakdown maintenance.

6. System Design Trends

Energy, environment and cost are presently dominating the conveyor belt industry. It is therefore timely that research and development be centred on these topics. Figure 4 illustrates a plan of activity that will generate new technology related to belt conveying. Figure 4 serves to summarise much of what has been discussed in this paper.

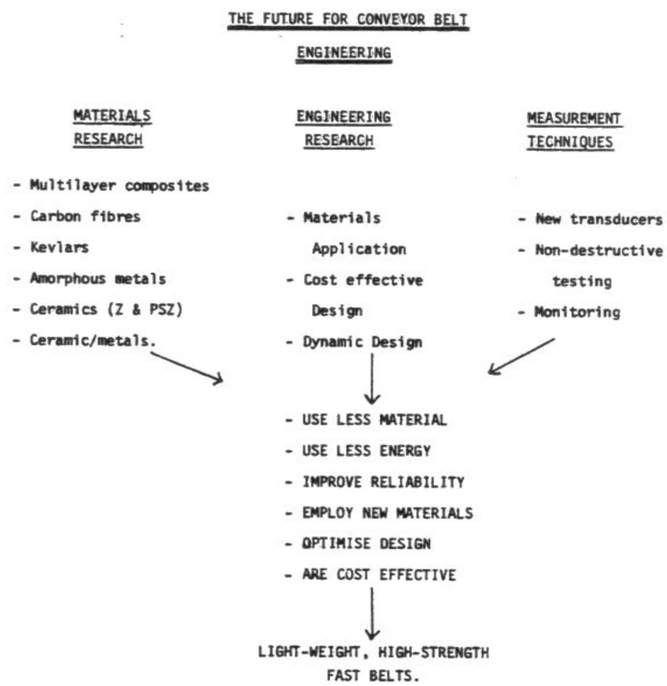

Figure 4. Three main areas of activity are necessary for the practical improvement of conveyors.

6.1 Energy losses

Energy and power is now costly. Improved design is necessary so that conventional conveyors will require less power to drive them over longer distances. An area of research at present is the investigation of rolling losses in the system using the concept of interaction between the belt and the idler trough geometry. It is now evident that the troughing idler angles should optimally match the transverse shape of the freely supported belt. This means that the system of idlers will uniformly contact the belt if the idler configuration is designed to match the troughability of the belt. Many users over-trough the belt to improve throughout with notable increases in power demand and wear. Fully loaded conveyors often will not start for this reason. A future paper on this topic will discuss the energy advantage of optimal trough shape in design.

A point not to be overlooked in design is the masses that constitute the rolling resistances. Light-weight belts using smaller SR rating steel-cord belts and new synthetic and other materials will reduce energy demand for belt systems and permit longer belts to be designed. Rotating idler mass and rolling resistance should be reduced further than at present. New light-weight high-stiffness composites could be used to replace steel idler shells. The use' of zirconia ceramics in bearing design could have significant cost advantages.

6.2 Environmental designs

Design engineers are well aware of the environmental impact of transportation systems. Noise, visibility, waterway pollution from runoff and dust are some obvious areas which need to be taken into account at the design stage.

It is presently feasible to design curved-belt systems such as used in Australia and at the SLN Nickel mine in New Caledonia. These systems cause least disruption to the environment, and can operate over greater than 10 km.

Unfortunately, few engineers have addressed themselves to the problem of design costing to take into account environmental interactions.

A new concept has been recently proposed that permits experimental economic analysis of conveyor belt systems using an interaction model approach [2].

Using this model it is possible to estimate the effects on the total system cost of varying certain interactions between the belt, structure, material and environment. Figure 5 shows an interaction model in which cost is central to the argument. To minimise the total cost, expensive cross interactions should be designed-out of the system. For example, belt vibration on return spans leads to the requirement for more costly idler bearings. This is an interaction between belt and structure. Design of a vibration free system eliminates this interaction and the associated cost.

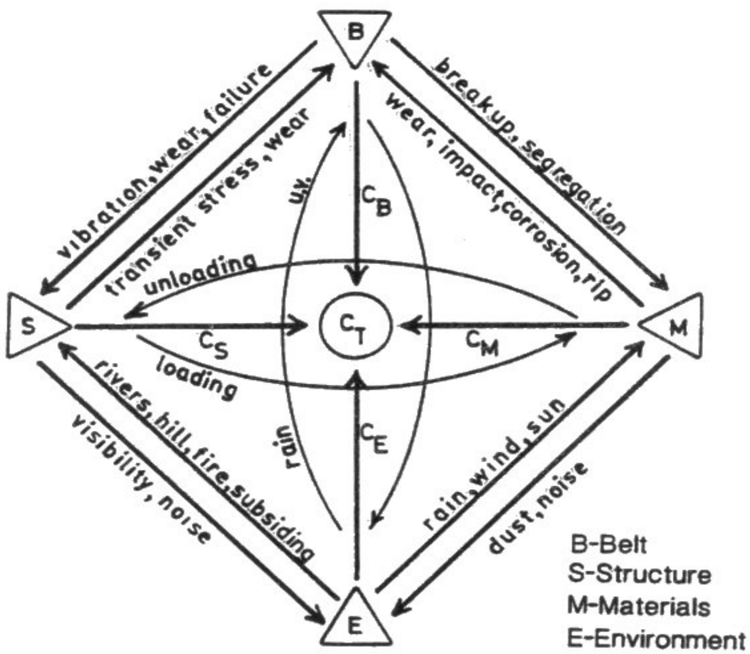

Figure 5. Interaction diagram for a belt system showing a total cost C_T based on each major system component.

Another interaction in this model occurs between the structure (drives) and the belt at starting and stopping. Using earlier arguments, a reduction in belt SF from 7:1 to 3:1 can be achieved by controlling the drive to produce smooth and continuous acceleration in the belt. A significant cost reduction of the total system can be achieved since the small increase in cost to control the belt speed is far outweighed by the lower belt cost component. Some energy saving is also achieved since the belt weight decreases as SF decreases in the cause of steel-cord belting.

The interaction of the belt system with the environment can lead to expensive designs such as buried systems with water drainage and housed belts to reduce noise and dust. One obvious design which overcomes many of the normally disruptive aspects of belts near population centres is the curved conveyor. Curved conveyors are more costly to install but by only a small margin over the cost of a straight system. Impact against the environment by not using this concept can lead to expensive relocation expenses for the population, as well as damaging valuable eco-systems.

7. Conclusion

This paper has attempted in a qualitative way to describe trends in the development of both technology and philosophy of conveying. We see that whilst the technologies of new materials, monitoring and design for fast belts will rapidly make their mark in the conveying industry, the social and economic aspects associated with the transport of bulk materials are being closely scrutinised.

Not only are costs directing the way in which research is evolving, as in the case of lower SF and weight for the belt design, cost is also dictating the viability of a belt system over other systems such as rail, road and pipeline. Research leading to improved designs which cost less to construct and operate can directly influence decision makers. Belt conveyors are now very competitive with truck and short haul rail, but with increased road building and up-keep costs, as well as increased fossil fuel costs, the continuous belt conveyor is now more attractive than rail and road for distances up to 30 km.

Improved design and use of new lightweight, high-speed and narrow belts make it feasible to operate troughed conveyor belts up to 100 km long. Monitoring technologies such as CBMs and rip detection form a vital component of the trends.

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