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Reducing Dynamic Loads in Belts powered by Three Wound-Rotor Motors

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9, 10 & 11 September, 1985
Landdrost Hotel
Johannesburg

The S.A. Institute of Materials Handling
The S.A. Institution of Mechanical Engineers
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REDUCING DYNAMIC LOADS IN BELTS

POWERED BY THREE WOUND-ROTOR MOTORS

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SUMMARY

Dynamic stresses are developed in large conveyor systems during starting and stopping. The magnitude of these stresses depends on the instantaneous belt velocity as the belt moves to or from its normal running velocity. This paper describes the procedure used to reduce the stress in a 5 km long steel cord belt to increase its working life. It details some practical solutions for reducing belt and structure stresses by the application of controlled starting and stopping of 3-phase, wound rotor slip-ring motors. In conjunction with this approach, modification to the mass take-up or pretensioning device may be required to achieve best performance.

1. INTRODUCTION

Large belt stresses may be induced by rapid changes in belt velocity during starting or stopping. Long steel cord belts develop very large dynamic tensions, particularly when the drive drum velocity falls very rapidly during stopping. Following switch-off of power to the driving motor, the belt speed progressively falls. In head-drive conveyors, the reduction in belt speed occurs along the belt at the speed of sound (1). Tension in the carry side progressively decreases as the system slows down. Tension in the return belt progressively increases due to a build-up of stress as the drive-drum slows down. The tension front is propagated along the return belt to tail of the belt. At this time, the stress in the belt at the drive or head-end reaches a maximum. A high stress front has been generated in the return belt and a reduced stress front has been generated in the carry side.

The wave-fronts generated by the stopping action cross through each other on the carry-side near the tail of the belt. A model describing this mechanism of stress propagation in conveyor belts was presented at Beltcon 2 in 1983 (1). Funke (2) and Nordell (3) have also investigated this problem.

This paper considers the causes of large dynamic loads in long conveyor belts. The paper will present a case study of a triple-drive system and show how large stresses may be reduced by controlling motor torque during starting or stopping and by adjusting the position of the tensioning device. In this example, switched-resistance motors are employed since they are well suited to torque control at high motor power and low motor speed.

2. SOURCES OF HIGH DYNAMIC LOADS

In conventionally designed belt systems there are three primary sources of dynamic loads which may affect the belt and structure during starting and particularly during stopping. They comprise large starting torques, long take-up loops with incorrect pre-tension and rapid belt deceleration.

3. MOTORS WITH LARGE STARTING TORQUE

Wound rotor motors with rotor resistance control offer one of the few possibilities of speed adjustment in a motor supplied with constant-frequency alternating current. Adding resistance to the rotor causes the motor breakdown slip to increase, however the torque remains constant at a reduced motors speed. The sudden application of power to all three motors of a large conveyor results in a rapid change of belt speed and generates large belt stresses due to the drum motion. Typically, 134% of rated torque may be simultaneously supplied by each of the three motors. Resistance is gradually switched-out of the rotor circuit as the speed rises.

A soft belt start may be achieved by supplying just enough motor rotor-current to achieve drive drum motion. Breakaway torques of near 105% of total rated torque should be a design aim. However, in practice starting torques of 67% for each motor may be achieved by open circuiting one phase of the rotor. In three-motor drive systems, two motors can be simultaneously started by this method and the third motor can be energised later.

The timing sequence for switching rotor resistance must ensure that torque steps do not coincide with the arrival of a tension wave-front on the carry side at the drive drum. Research supported by field measurements has shown that rotor resistance should be reduced in steps with each step corresponding to the time for the previous tension wave-front to propagate around the whole belt (4). The control of belt speed by the control of motor torque may result in the elimination of dynamic circulating stresses, particularly when optimum control is employed (1).

Figure 1(a) illustrates a conventional starting sequence for a large conveyor system powered by three wound-rotor motors and also shows the resultant belt speed. Note that the second current step for two motors coincides with the arrival of the tension front generated by the initial application of 150% rated torque from all three motors. The third motor step is also incorrectly timed in relation to the elastic wave period and causes additional belt stresses. The timing of the third step is conducive to stress reduction.

Figure 1(b) illustrates a correctly timed sequence to minimise the generation of transient stresses in the belt. In this example the start of motor M3 is delayed and the torque is reduced in motors M1 and M2 at start by open-circuiting one rotor winding to produce 67% starting torque.

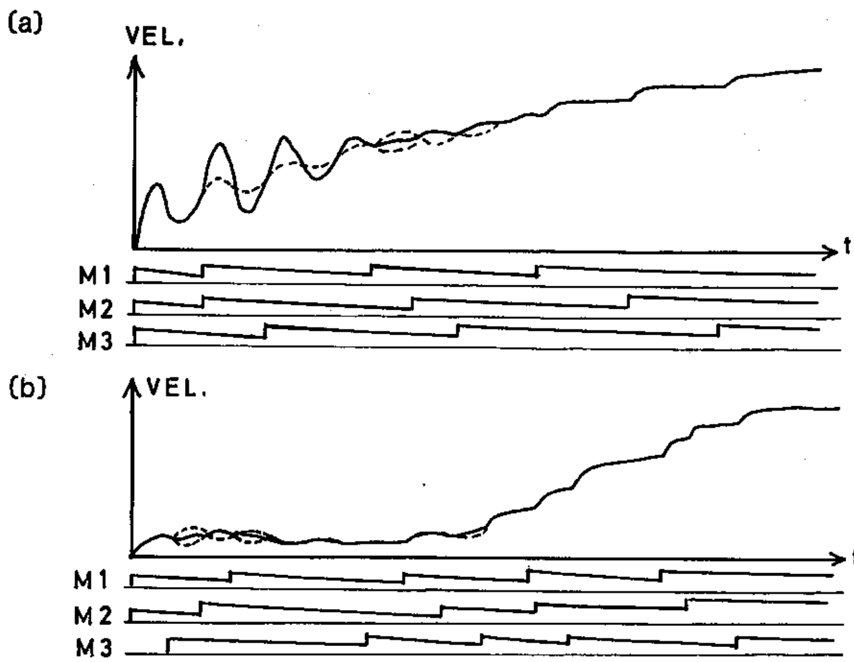

Figure 1. Velocity-time curves showing motor sequencing which produces:
(a) Constructive reinforcement of belt stresses.
(b) Destructive interference of belt stresses.

4. LONG TAKE-UP LOOPS

Long loops of belting in the pre-tensioning system cause problems during starting and stopping due to the in-rush of belting into the return of the conveyor. In particular, this effect is most noticeable in flat and inclined conveyors with head pre-tensioning utilising gravity take-up masses. Automatic tracking winches cause similar effects, however, fixed-winch pre-tensioning at the head prevents the in-rush of extra belting toward the conveyor tail.

During the start-up of gravity take-up systems, the gravity take-up moves down as the drive drum rotates. If the return belt tension is less than the mass take-up force the return belt does not move until the stress in the carry side has propagated around the whole belt. At this point the take-up mass is required to move up as the return belt surges to a substantial proportion of the final belt speed. The stress in the belt and structure of this type of design maybe 10 times the static stress (1). A long take-up loop in this situation causes instabilities in the belt at the tail due to the need to accommodate the extra belting as the return belt surges around the tail pulley and catches up with the carry-side belt. A small differential velocity causes severe belt sag and material spillage as the belt is pulled tight by the continuing drive tension. This effect also occurs at conveyor shut-down.

One solution would involve increasing the belt pre-tension. Another solution would involve reducing the length of the loop in the take-up. The former solution will cause design problems especially in the setting of belt sag for optimum rolling resistance during operation.

Reducing the length of the belt loop in the gravity take-up may also cause operational problems in long steel-cord belts, and so three other solutions maybe offered to remove take-up problems. Firstly, use a fixed-winch pre-tensioning system during starting and stopping but allow the winch to adjust belt tension during running. Secondly, install a mass take-up at the tail or at the location of lowest tension in the system. This solution may not be practical in underground installations and a winch may be preferable. Thirdly, install a hydraulic buffer at the head-end gravity take-up and move the tail pulley back so that most of the belting in the take-up loop is removed. The moveable gravity take-up should push against the buffer to provide a small additional tension in the belt. A reduction in take-up mass may now be achieved since the effective belt tension is increased by the buffer. To illustrate the application of the third possibility described above, a 5 km long steel cord belt take-up was modified to reduce excess belt in the return run. In addition, starting torque was reduced.

4.1 EXAMPLE CONVEYOR

Figure 2(a) shows the original conveyor and figure 2(b) shows the belt velocity characteristics for the unloaded belt. At startup, 134% rated torque was supplied by each motor and the 20 tonne mass lowered. Next, the return belt surged away with an acceleration of 5 m/s^2, some 7.6 s after the carry side sensor S1 detected start-up. The stress in the return belt pulling against the mass take-up approaches 1000 kN, lowering the belt safety factor for the SR2400 steel cord belt to near 2.4. Furthermore, the loop take-up provided an additional 24 m of return belt which caused severe tail buckling and material spillage. This particular example was discussed in detail in a previous paper (1). During stopping, the return belt continues to move at normal belt speed as the 20 tonne mass take-up rises until the mass collides with the structure. At this time the speed of the returning belt rapidly falls. In this example, large static stresses occur in the return belt, though the presence of elastic waves in the belt results in two cycles of higher dynamic stress in the carry-side during stopping.

4.2 MODIFIED DESIGN

Figure 3(a) illustrates the modified system. The conveyor tail pulley was moved back to remove excess belt from the loop take-up. An hydraulic 20 tonne buffer was installed on the mass take-up and the buffer was used to increase average belt tension by up to 15 kN as the tail was pulled back. The take-up mass was reduced to 13 tonne. In addition, the starting torque of each motor was reduced from 134% to 67% rated torque. At start-up the carry and return belt now move away together and the take-up mass falls about 1 m from its static position. The peak return belt acceleration during starting was reduced to 1.1 m/s^2, as illustrated by figure 3(b). The average running power increased from 900 kW to 960 kW with the increased static tensions, however dynamic tensions were significantly reduced by lowering starting torque.

During stopping the carry and return belts slow down together and the mass take-up fully compresses the buffer. In figure 3(b) the stopping curve (botom trace) has been modified by reducing power to the motors. In the particular run shown, A and B represent the insertion of rotor resistance, while at time C all motors are turned off. The run-down velocity from time C to the stopped condition has the same slope as the original system. The controlled stop has reduced dynamic stresses but increased stopping time. Increased stopping time is not desirable for safety reasons and a solution will be discussed in the following section. The combination of mechanical modification and powered stopping results in a very smooth run-down of the belt at the drive.

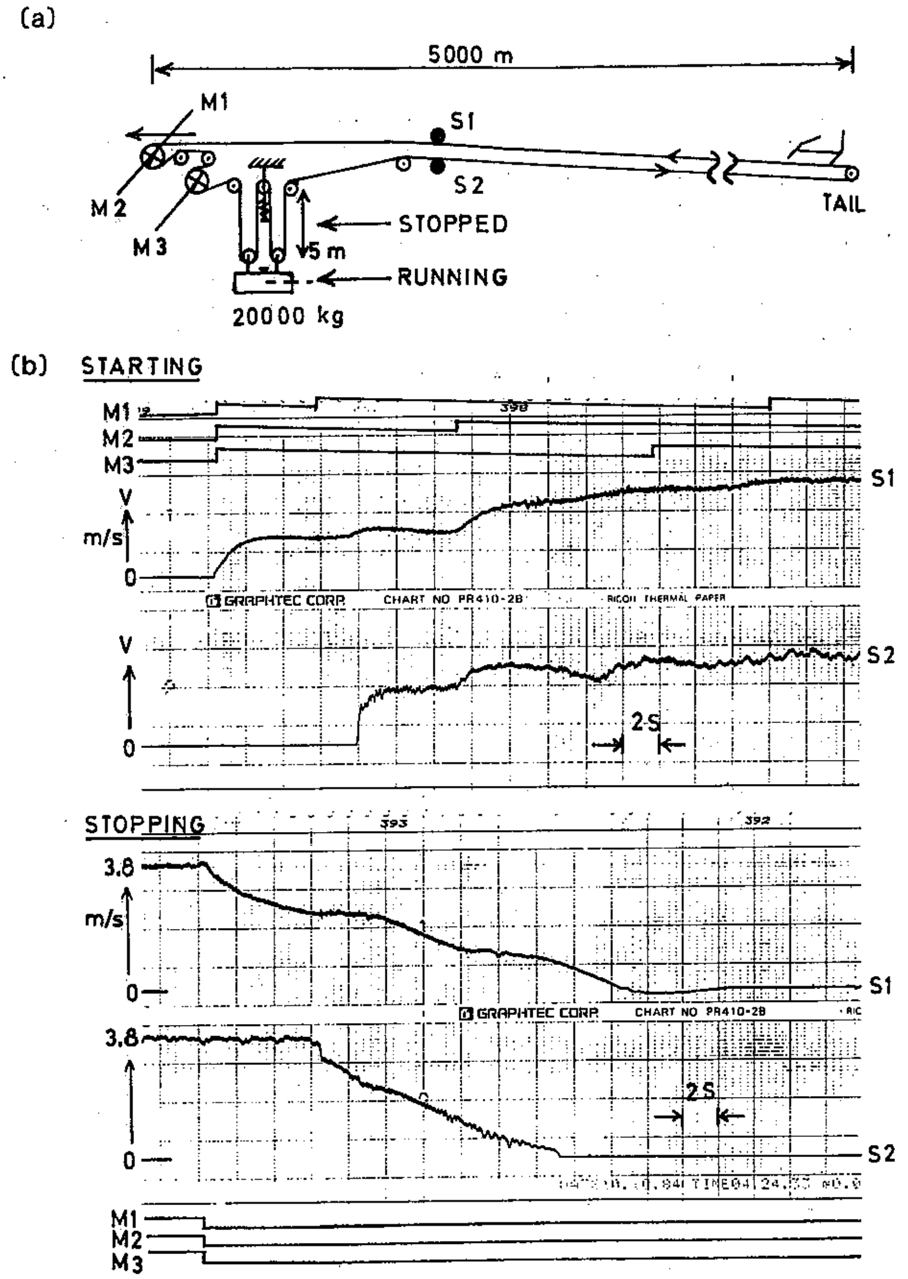

Figure 2(a) Cross-section of a long conveyor driven by three wound-rotor motors.

(b) Starting and stopping velocity-time curves (upper two traces and lower two traces respectively), measured with sensors S1 and S2 at the locations shown in figure 2(a). The belt was unloaded.

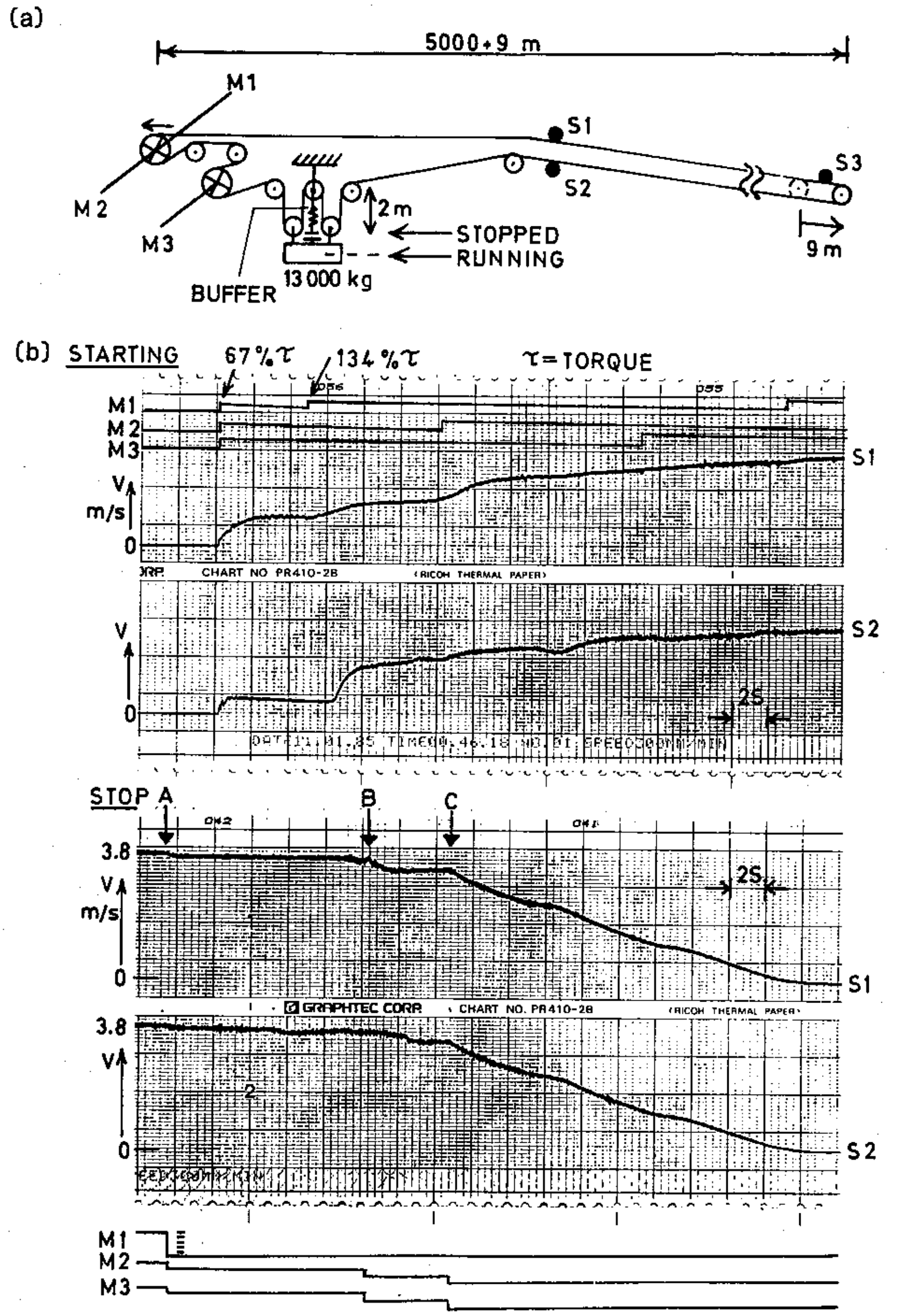

Figure 3(a) Modified conveyor system.

3(b) Starting characteristics (upper two traces) and stopping characteristics (lower two traces) forthe modified system with the belt unloaded. Trace signals S1 and S2 were recorded from sensors S1 and S2. The stopping curve shows the effect of reducing motor torque by inserting rotor resistance.

4.3 TAIL DYNAMICS AT START-UP

Measurement at the tail of the belt in relation to the head of the conveyor provides valuable additional information with regard to carry and return wave times and the tail belt velocity behaviour.

Figure 4(a) illustrates the starting curves for the empty belt at the head location S1, at the tail S3 and at the return S2. These curves show the motion of the tail in relation to the head end of the conveyor. The starting curves for the loaded belt are illustrated in figure 4(b). The motor current steps are included to show the relation between increased motor torque and belt velocity. The peak accelerations for the unloaded belt are typically 1.6 m/s^2 on starting and the actual stress in the belt is large compared to the stress in the fully loaded belt which accelerates at 0.54 m/s^2. Using a wave method (1), the dynamic belt stress on start-up is calculated to be 136 kN for the unloaded belt and 86 kN for the loaded belt. These dynamic tensions are added to the static tensions in the belt.

In addition to being able to reduce starting stresses by the correct design of take-up structure, correct design of take-up and belt pre-tension also reduced the stresses at the conveyor tail.

5 CONTROLLED STOPPING

The belt system described in figure 3 has been further modified to reduce stopping time and stresses by controlling the stopping sequence. This has been achieved with wound-rotor motors by the selective insertion of resistance into the rotors. The speed decreases while maintaining full load torque up to the point where the slope of the controlled curve is similar to the slope of the normal rundown curve. This process minimises belt jerk (1).

Referring to fig.3(b) (lower trace), the motor speed was reduced by the following procedure:

(i) disconnecting all power to motor M1 at time t = A.

(ii) Reducing the torque of motors M2 and M3 to (each motor has five resistance steps) 4/5 of full load torque at time t = A.

(iii) Reducing the torque of motors M2 and M3 to 2/5 of full torque at time t = B.

(iv) All power off at time t = C.

The belt speed decreases to a fixed value without the generation of elastic waves in the belt at times A and B.

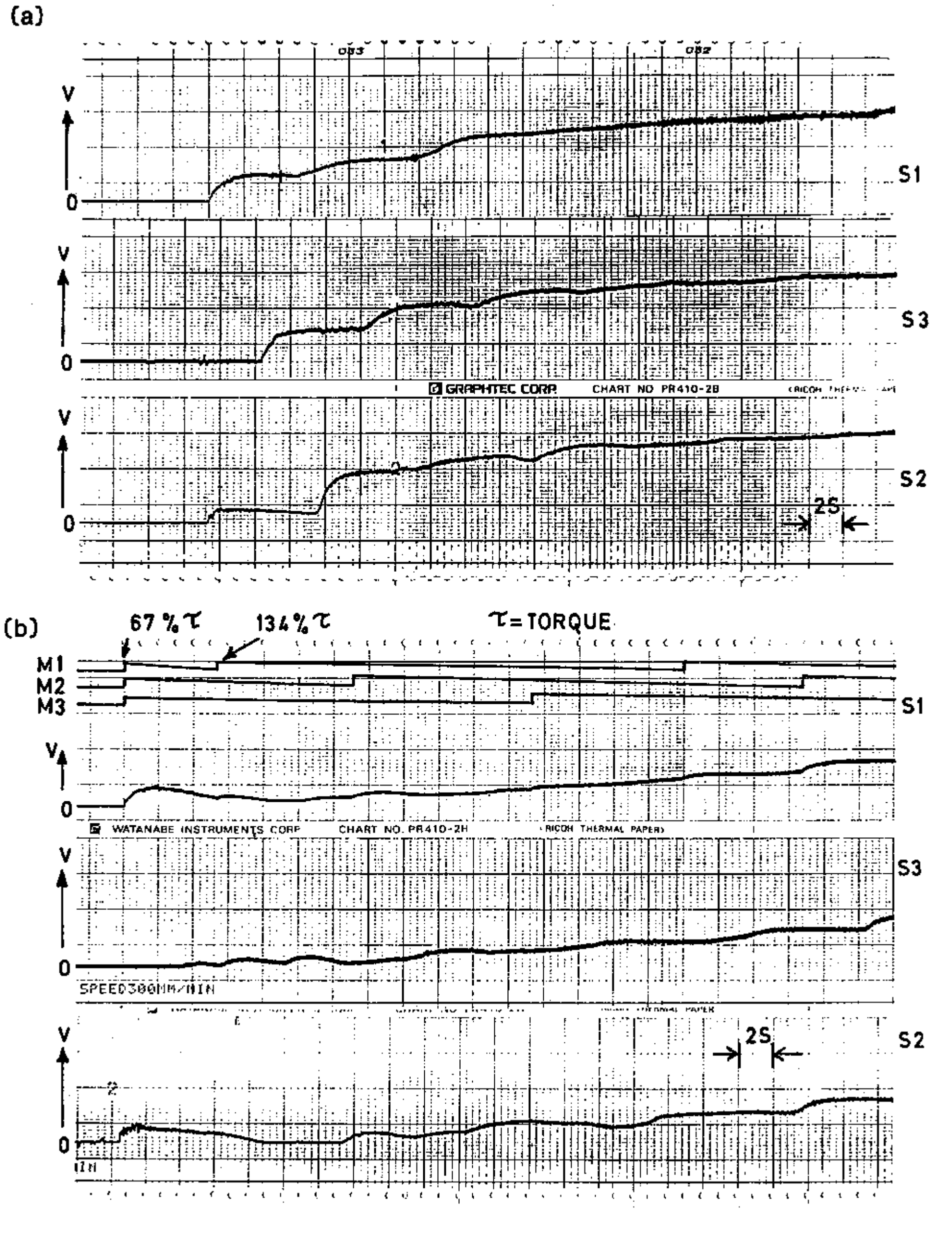

Figure 4. (a) Starting curves at S1, S3 and S2 for the unloaded belt.

(b) Starting curves at S1, S3 and S2 for the loaded belt, including the timing sequence for the motor steps.

Since the wave cycle around the belt takes about 3.5 s, the points B and C should be about 3.5 s apart. Further, since no wave is generated at A, the onset of B can be soon after A, but for the installed example, a minimum delay of 2 s is required between steps.

The stopping procedure above provides a practical solution to the controlled stopping of the empty belt. The stopping time was increased by only 5.5 seconds in this case. Experience has shown that these settings are also appropriate for the stopping of loaded belts since the average wave period only increases slightly by loading (4).

Figure 5(a) illustrates a full speed controlled stop for the unloaded belt using the optimum timing. Notice that elastic waves are eliminated at stopping, and there was only the slightest evidence of wave behaviour at the tail. Figure 5(b) illustrates a powered stop for the belt with a load throughput of 700 t/h.

In figure 5(a) and 5(b), the upper, middle and lower traces represent belt speed signals from the head (carry) S1, tail S3, and head (return) S2 after initiating the stop. The fourth trace included in figure 5(b) represents the output of a 600 kN load cell placed between the mass take-up and the hydraulic buffer ram to measure the structure force due to the return belt in-rush at stopping. The peak load is 330 kN in the belt and this load is imparted to the structure. The return belt tension is 30 kN and the carry side tension is 250 kN. Following connection of the mass with the buffer at stopping, the dynamic belt tensions oscillate, peaking at 330 kN and settling out at 220 kN.

The behaviour of the conveyor tail during the stopping period for the loaded belt is quite acceptable when a controlled stop is employed. These modifications have been successful in preventing material spillage at the tail by removing the possibility of slack-belt belt on stopping. Additional steps may be employed to provide an even smoother rundown at the expense of increased stopping time.

6. UNCONTROLLED STOPPING AND ABORTED STARTING

Power failure in conveyor systems will result in uncontrolled stopping and larger dynamic loads. An aborted start during the run-up period may also result in very large dynamic loads, especially if it cannot be followed by a powered run-down. It is generally accepted that aborted starting leads to worse-case stress conditions in the belt and structure. An investigation of these conditions was carried out.

In the case study example, worse-case power failure and aborted starting were simulated during the run-up sequence. The belt drive motors were disconnected from the power at 95% full

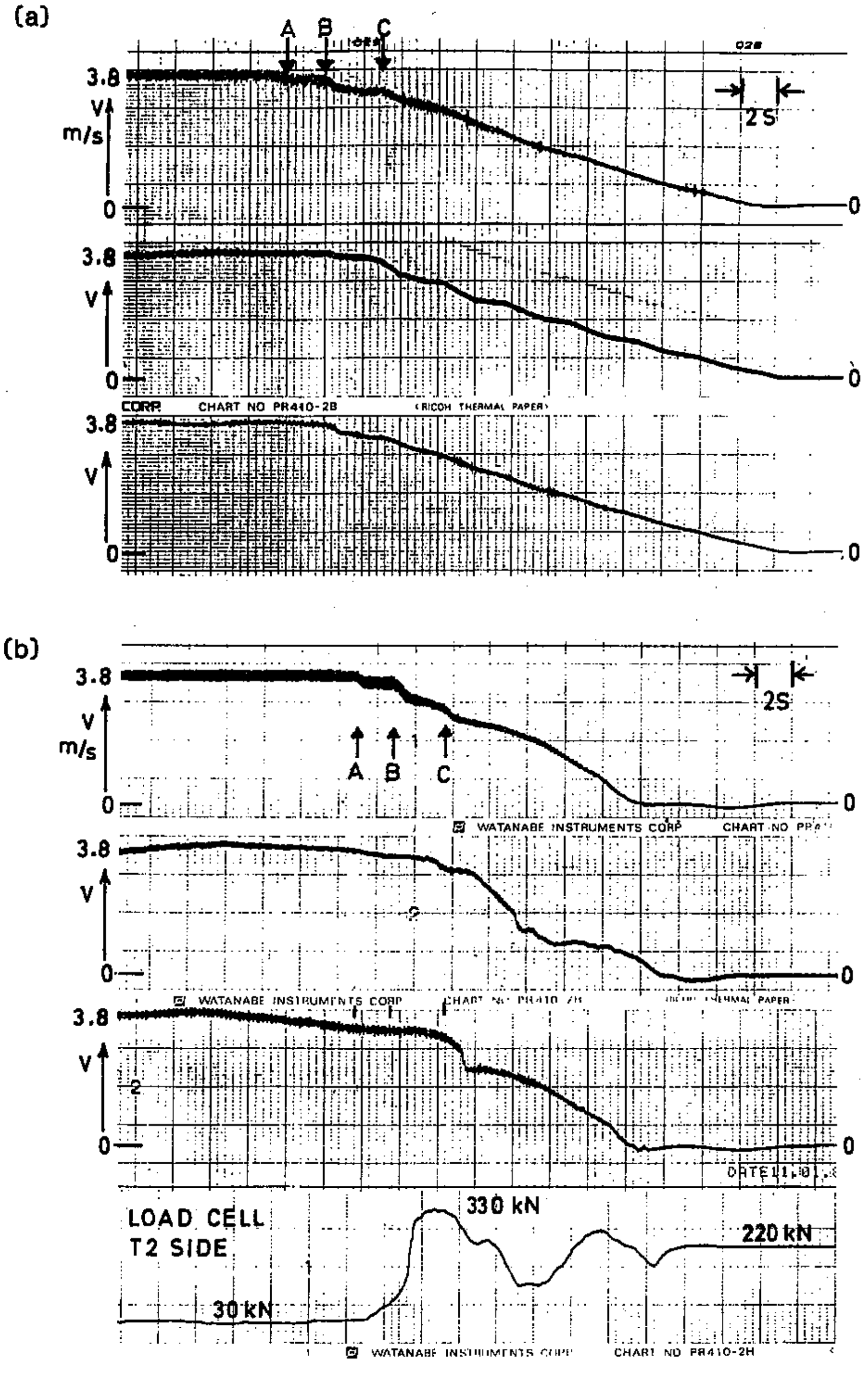

Figure 5. (a) Stopping characteristics of the unloaded belt at sensors S1, S3 and S2, using controlled stopping.

(b) Stopping characteristics of the loaded belt at sensors S1, S3 and S2 with controlled stopping, including load cell output for the take-up mass.

speed. Figure 6(a) illustrates the dynamic velocity component present in the belt during unloaded run-down, measured at the head carry side (S1), the tail (S3) and the head return side (S2).

Figure 6(b) represents the worse-case stress conditions in the belt. At the head (carry side) the peak deceleration is 2 m/s^2. The calculated return belt stress at S_2 is 337 kN of dynamic load which when added to static tension in the belt of 90 kN results in a full-load aborted-start stress of 427 kN. This load is nearly half the peak return belt tension of 740 kN (1) of the original design described in Section 4.1 and shown by figure 2. During a worse-case aborted start, the tail belt velocity drops to zero very rapidly after 3 seconds, then runs back as the tightly stretched return belt pulls on the relatively compressed belt, resulting in the negative velocity. After another 3 seconds, the belt runs forward rapidly. This behaviour is explained by circulating elastic waves in the belt. However, when belt run-back causes a great deal of slack belt as the result of low design pre-tension, material spillage will still occur at the tail. Spillage has been eliminated in this example since severe tail belt buckling is prevented by the modifications to the take-up system.

7. WINCH TAKE-UP SYSTEMS

Winch take-up assemblies serve a valuable role, particularly in underground mines since they require less room to install. Fixed-winch pre-tensioning is preferred during starting and stopping, though the winch may be allowed to track belt tension during operation. Unless the dynamic behaviour of the belt is exactly known for all conditions of load, it is very dangerous to expect the winch to track dynamic tensions automatically, during stopping in particular, and to maintain uniform belt and structure load. The phase between the winch action and the belt motion is critical if higher stresses are not to be induced into the structure. The response of load cells and the processing circuit must be very fast, so that a winch motor may quickly respond to changing loads. Typically, a response time of 0.25 s or better is advisable in systems in which automatic tracking is desired.

8. CONCLUDING COMMENTS

Methods for reducing dynamic loads during starting and stopping of conveyors have been discussed with the aid of an example. Though a number of authors have investigated the dynamic behaviour of conveyor belts during starting and stopping, the practical application to conveyors needs to be continuously presented to industry. At present, there is an emphasis on reducing costs due to downtime and failure, particularly in longer belt systems. This paper has highlighted by way of example the value to be gained by the application of design

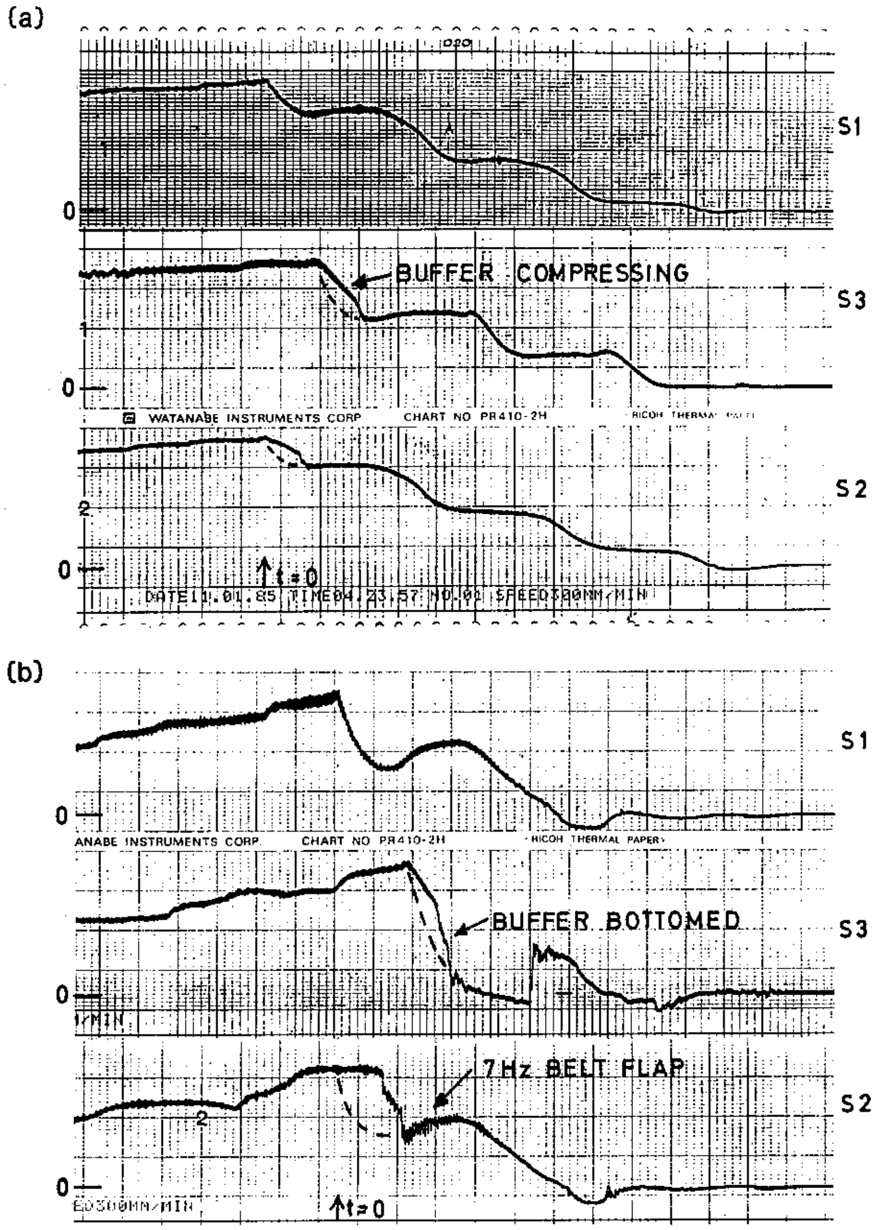

Figure 6 (a) Aborted start for the empty belt without controlled stopping, with motors M_1, M_2 and M_3 all off.

(b) Aborted start for the fully loaded belt without controlled stopping and with all motors off at t = 0

The dotted lines indicate the response with out a hydraulic buffer.

improvements in conveyor systems, and in particular the production of soft stops using slip-ring motors.

REFERENCES

1. Harrison, A., Criteria for minimising transient stress in conveyor belt. Proc. Beltcon 2, Johannesburg, May 1983.

2. Funke, H., The Dynamic stress of conveyor belt systems during starting and stopping. Braunkohle N3 V26, p.64-73, 1974.

3. Nordell, L.K., Ciozda, Z.P., Analysis of starting and stopping high strength, high capacity belts using modern engineering tools. SME-AIME. Annual Meeting, Los. Angeles, Cal. Feb. 26-Mar.1. (1984).

4. Harrison, A. Stress front velocity in elastomer belts with bonded steel cable reinforcing. J. Mech. Eng. Sci. (in press).

ACKNOWLEDGEMENTS

The author wishes to thank Elcom's Newvale colliery and the Bellambi colliery for providing installations and for applying concepts developed in this paper. He thanks H.W. Kinnersly of CSIRO for helping with underground measurements. This paper was presented at Beltcon 3, S. Africa, with the kind permission of the editor of Bulk Solids Handling, Dr R. Wohlbier.