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BELTCON 3

Longitudinal Stresses occurring in Long Conveyor Belts during Starting and Stopping

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LONGITUDINAL STRESSES OCCURRING IN LONG CONVEYOR BELTS DURING STARTING AND STOPPING

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C O N T E N T S

S U M M A R Y

High transient stresses during starting and stopping a conveyor can cause tremendous harm to a conveyor system, resulting in belt and structure damage and belt splice and pulley failures.

In some cases, it is difficult to measure these stresses and hence their presence may go undetected, resulting in low availability and high running costs of the conveyor system.

A number of in-depth papers have been published on this subject, with various mathematical models being proposed.

This paper concerns a case study on a conveyor belt suspected of having high transient stresses. The measurements taken are analysed with simple corrolation to the mathematical models, and solutions to reduce or eliminate the stresses are discussed. A second case study is also briefly discussed.

Horizontal belt - distance between centres: 950 m

Belt type: PVC fabric, Class 1250, 1 200 mm wide

Design tonnage: 1 500 T.P.H.

Solid winch take up.

2.1 Starting the Conveyor

Constant fill fluid couplings with direct on-line squirrel cage motors (D.O.L. S.C.M.) are used to start and drive the conveyor.

If the conveyor system was assumed to be a constant torque machine (i.e. the torque required to drive the belt is constant at any speed) and the system inertia assumed to be a solid body (i.e. no belt stretch), a conveyor start could easily be calculated or simulated.

Such a simulated start is shown in Figure No. 2, with a single fluid coupling coupled to a D.O.L. S.C.M.

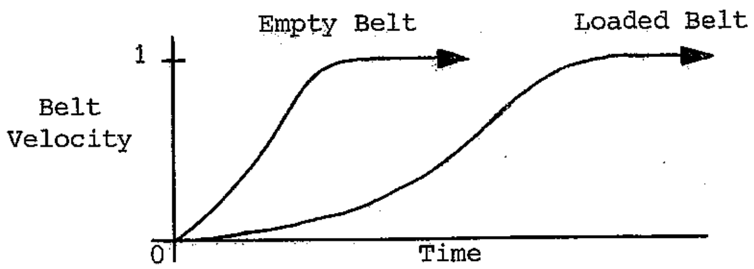
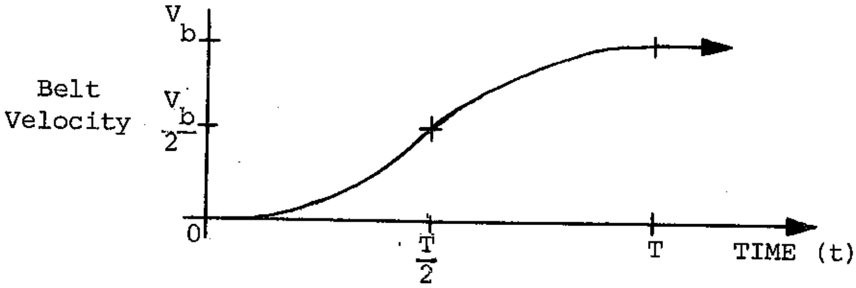


Figure No. 2: Simulated Velocity Profiles

The empty belt velocity profile (and the loaded belt profile to a lesser extent) is very similar to the start-stop characteristic proposed by Dr A. Harrison to minimise stress in the belt (Ref. 6.1). This is shown in Figure No. 3 (note the symmetry of the curve). The belt reaches half speed after half the start-up time.



$$V(t) = \frac{V_b}{2} \left(1 - \cos \frac{\pi t}{T}\right)$$

Figure No. 3: Velocity Profile for Minimum Stresses

In reality, however, a conveyor is not a constant torque machine and the belting is not rigid at all.

The velocity profiles actually measured for the conveyor are shown in Figure No. 4.

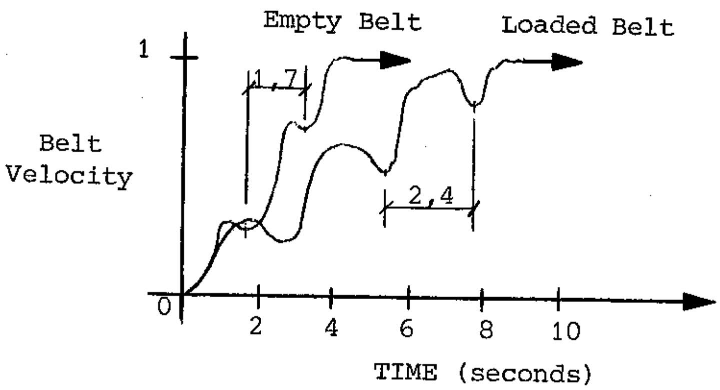


Figure No. 4: Measured Velocity Profiles and Oscillation Periods.

These velocity profiles clearly indicate the presence of some sort of shockwaves. The almost instantaneous changes in belt speed suggest that the shockwaves induce extreme stresses in the belting.

The speed V_s at which the shockwave moves through the belt can be calculated as follows:

$$V_s = \frac{\text{Distance for wave to travel from head to tail and back again}}{\text{Time for one shockwave oscillation (period)}}$$

$$= \frac{2 \times \text{Belt Centres}}{1 \times \text{Period}} \quad \begin{matrix}(m)\\(sec)\end{matrix}$$

For the empty belt (lower run), the shockwave velocity is:

$$V_{se} = \frac{1\ 800\ m}{1{,}7\ sec} = 1\ 060\ m/s$$

For the loaded belt (top run), the shockwave velocity is:

$$V_{sl} = \frac{1\ 800\ m}{2{,}4\ sec} = 750\ m/s$$

The shockwave velocity in the top run is less because of the dampening effect of the material.

The occurrence and magnitude of these shockwaves is ultimately dependent on the time ratio TA/Tu determined from the lower run wave period Tu and the time TA typical for any variation in torque released by the drive. (Ref. 6.2.)

The lower run wave period Tu is 1,7 seconds and cannot be altered - it is dependent on the belt type and belt length only.

So, for any specific conveyor, the occurrence and magnitude of the shockwaves is dependent on the time TA for the torque build-up to accelerate the belt.

Hence, the longer the torque takes to build up to its maximum, the less the severity of the shockwaves on the system will be.

2.1.1 Loaded Belt

Now consider the sequences and limitations of various starting methods actually used in the case study with a loaded belt:

(1) Original couplings with both drive motors being energized simultaneously.

(2) Improved coupling design fitted, but still with simultaneous motor energization.

(3) Improved coupling design, but with 3 second time delay between energizing Drive 2 and Drive 1.

Refer to Figure No. 5 (overleaf).

Note: The motor current of Drive No. 2 was monitored as a measure of the torque or stress in the belt during acceleration. (At full motor speed, torque is approximately proportional to current, and torque is directly proportional to the accelerating forces in the belt.)

FIGURE NO. 5

ORIGINAL DUAL START

Torque T

1. Rapid build-up to maximum torque (approx. 2 seconds).
2. High maximum torque.

Current I

High starting current with large oscillations.

Belt Velocity V

1. Rapid start-up to full speed (10 seconds).
2. Severe velocity changes.

IMPROVED DUAL START

Torque T

1. Rapid build-up to maximum torque (approx. 2 seconds)
2. Reduced maximum torque.

Current I

Reduced starting current with longer period oscillations.

Belt Velocity V

1. Longer start-up time (15 seconds).
2. Less severe velocity changes - only in first 5 seconds.

IMPROVED DELAYED START

Torque T

1. Gradual build-up to maximum torque (approx. 5 seconds).
2. Reduced maximum torque.

Current I

Reduced starting current with minor oscillations.

Belt Velocity V

1. Longer start-up time (16 seconds).
2. No velocity oscillations.

Note: The velocity profile is almost identical to that for minimum stress in Figure No. 3.

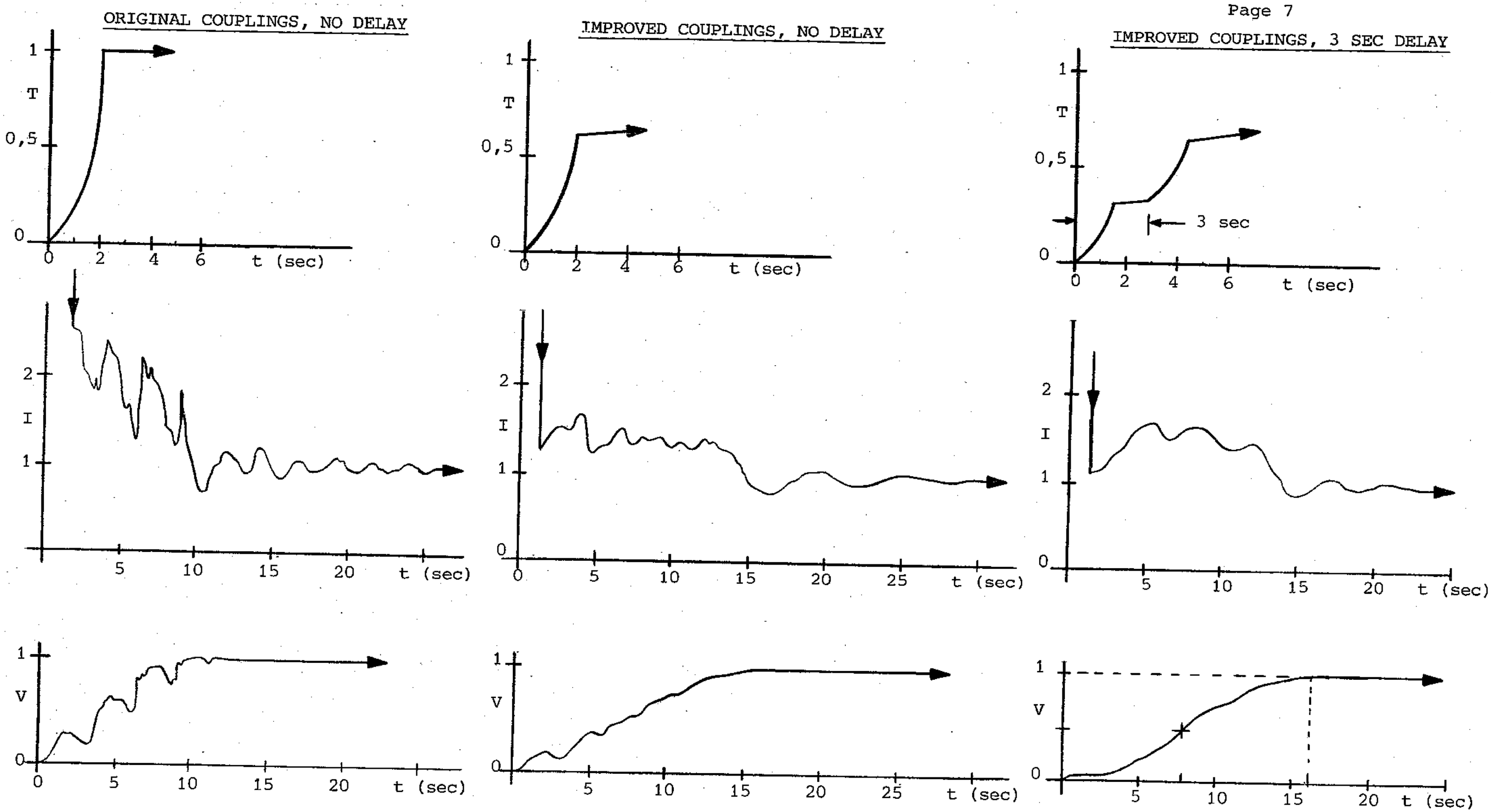


FIGURE NO. 5: COMPARISON OF DIFFERENT STARTING METHODS: LOADED BELT

LEGEND:
T: Theoretical total starting torque
I: Motor current - Drive No. 2
V: Belt velocity

<u>Comparison of motor currents between the two couplings with no time delay between starting of drives</u>

A more detailed comparison of the current is possible by studying Figure No. 6. By superimposing a dampened harmonic motion function onto each graph, a clear similarity is seen between theoretical and actual measurements in the latter half of the curves (after t = 10 seconds).

By extending the mathematical curves closer towards the start (t = 0 seconds), the oscillating stresses in the belt could be predicted as shown.

Note the differences in period of oscillation and in maximum amplitudes.

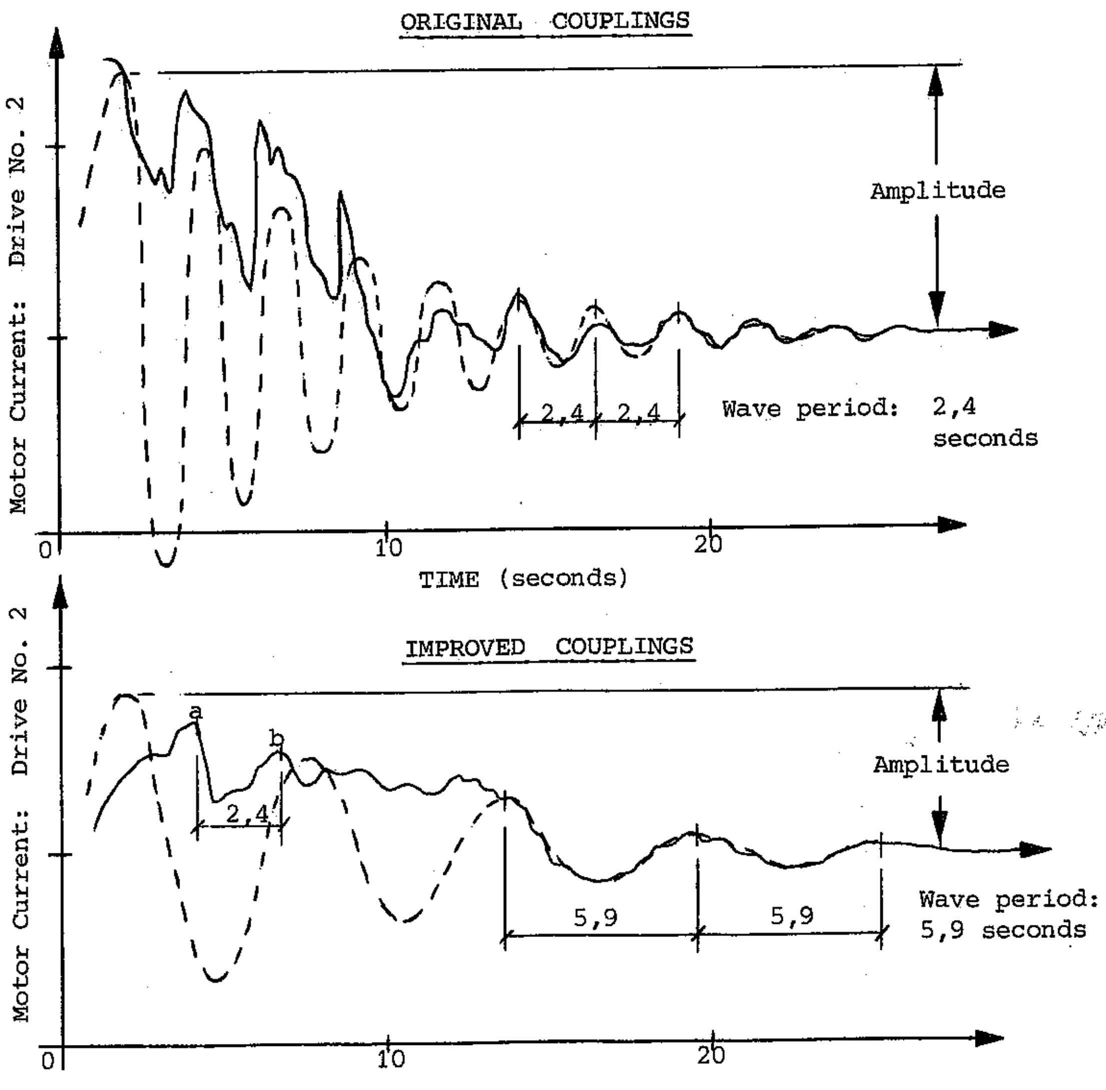
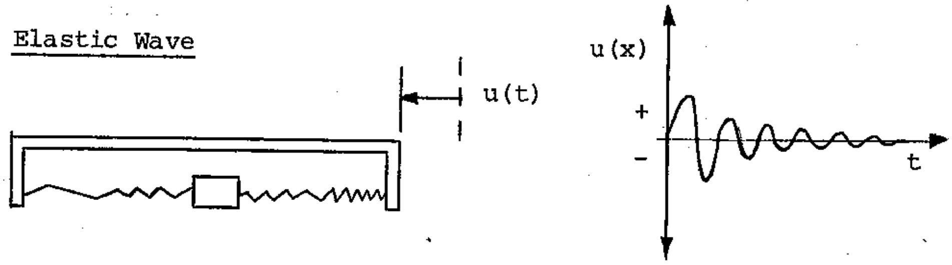


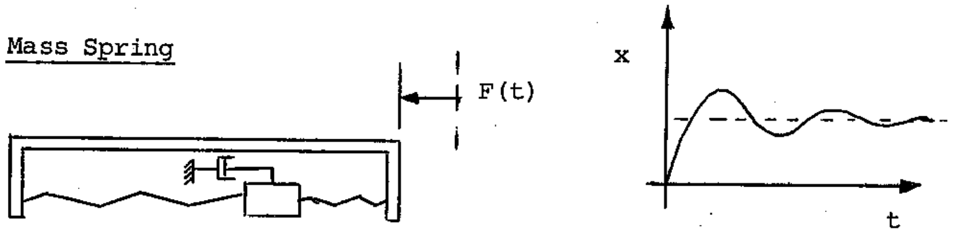
Figure No. 6: Comparison between Original and Improved Couplings - Dual Start - Loaded Belt

Dr A Harrison identified the presence of two distinctly different types of oscillations occurring during starting or stopping a conveyor.

The two solutions are given in Figure No. 7.



$$u(x,t) = k.\sin\omega t.\cos\beta x.e^{-\gamma t}$$



$$F(t) = m\ddot{x} + c\dot{x} + kx$$

Figure No. 7: Model Solutions

By comparing these solutions to the actual curves in Figure No. 6, it can be seen that for the original couplings the elastic wave oscillation dominates, with a period of 2,4 seconds.

For the improved couplings, the mass spring oscillation dominates, with a period of 5,9 seconds, with only a slight presence of the elastic wave of period 2,4 seconds at points a and b.

In comparing the respective belt velocity profiles (ref. Figure No. 5), it can be concluded that the mass spring oscillation does not impose any severe stresses during starting of the conveyor.

However, the elastic wave oscillation is responsible for the high starting stresses in the conveyor belt.

The stresses imposed by the mass spring oscillation can be ignored when compared to those imposed by the elastic wave oscillation (Ref. 6.1).

3.1.2 Empty Belt

The test results for the empty belt start are shown in Figure No. 8. Note: The theoretical total starting torques have been omitted, but are the same as for the loaded belt (see Figure No. 5).

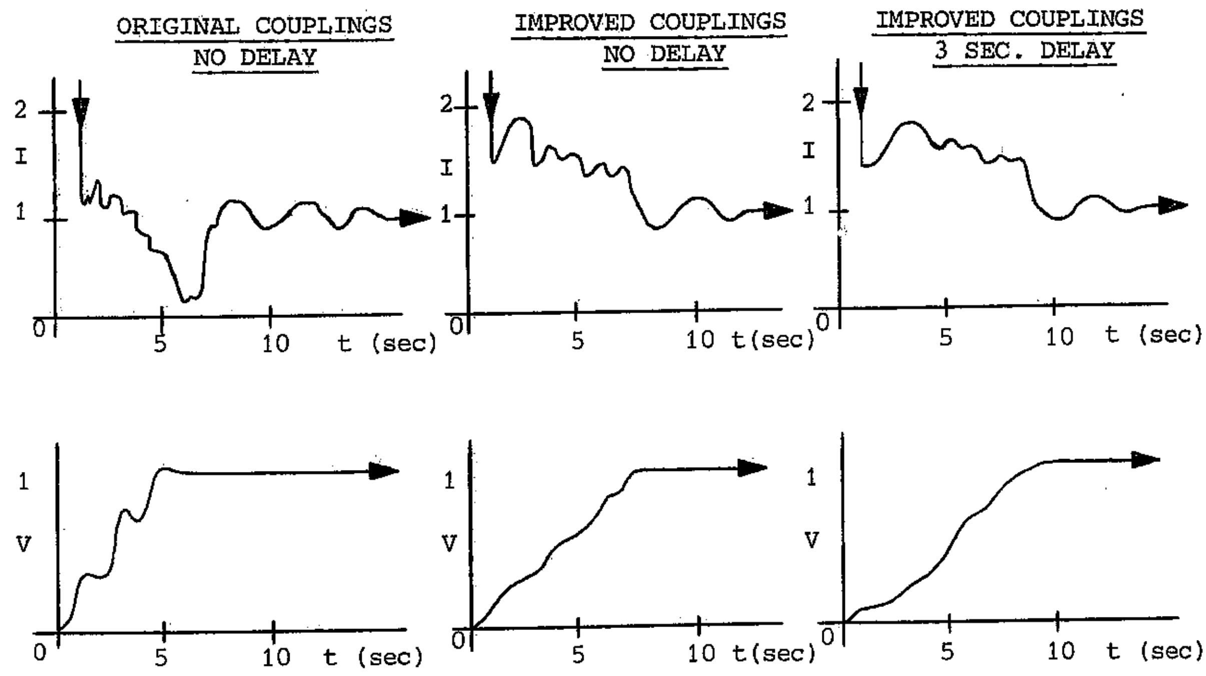


Figure No. 8: Comparison of Different Starting Methods-Empty Belt. Legend: I = Motor current - Drive No. 2
V = Belt speed

The velocity profile results indicate the presence of a similar shockwave with the original couplings, with a rapid start-up time of 4,5 seconds.

With the improved couplings and a time delay of 3 seconds, the shockwaves have been almost completely eliminated, and the starting time extended to 8,5 seconds.

The motor current results are more difficult to interpret, but by comparing the peak currents for the empty starts (Figure No. 8) to those for the loaded starts (Figure No. 5), it is evident that the starting stresses are more severe for a loaded start than for an empty start.

3.2 Stopping the Conveyor

Oscillations can also be induced in the belt during the stopping mode, although the resultant stresses would normally not be as severe as those occurring during the starting mode.

For stopping the belt, the motors are de-energized and the torque magnitude is negative and equivalent to the running torque at that moment.

The rate at which the torque is removed when the motor/s de-energize is difficult to realise as the motor/s still have a large inertia even after being fully de-energized.

Figure No. 9 shows a comparison between the theoretical rate and magnitude of the starting and stopping torques for loaded and empty belts and actual velocity profiles measured for the stopping of the belt.

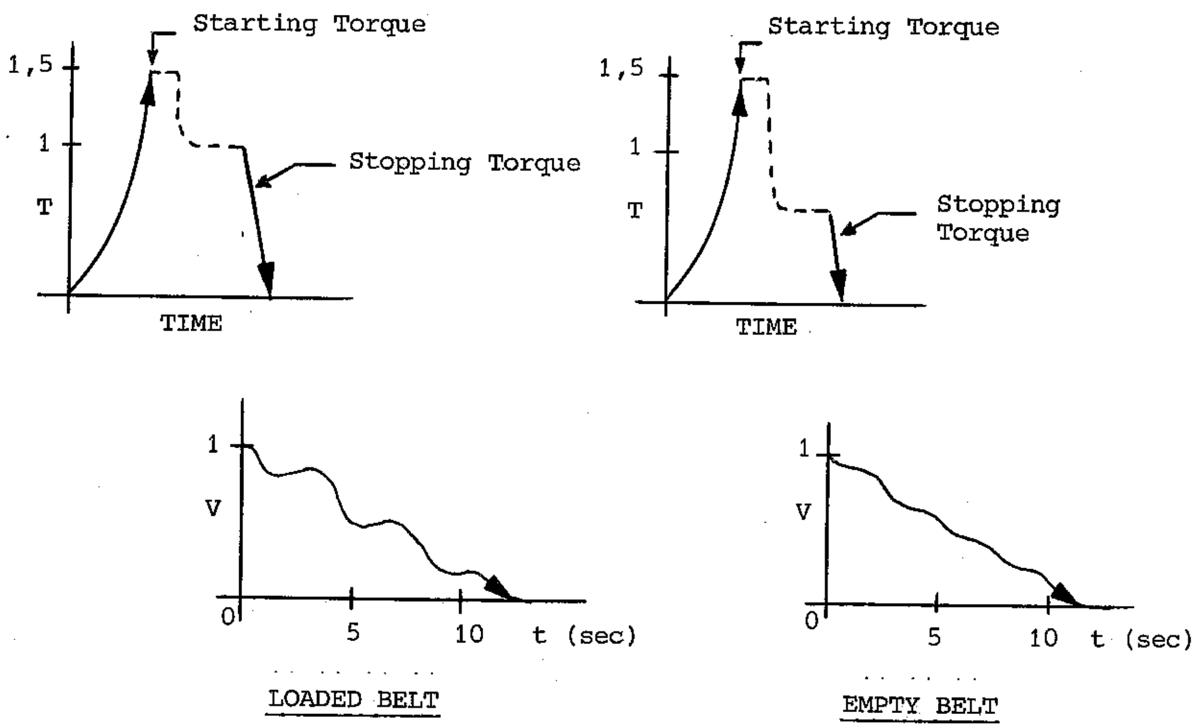


Figure No. 9: Comparison of Velocity Profiles during Stopping - Loaded and Empty Belt

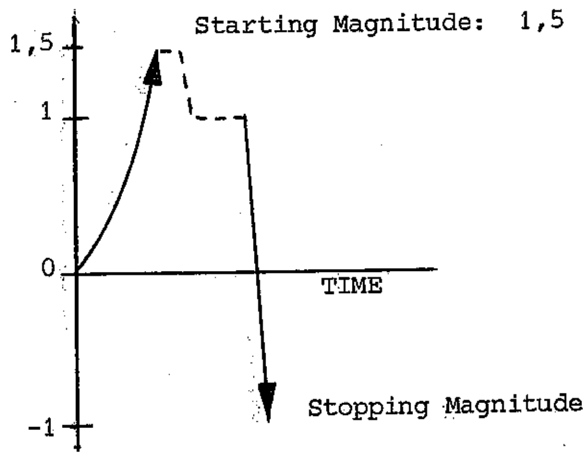


Figure No. 10: Comparison between Starting Torque and Braking Torque - Rate and Magnitude

Obviously, now the magnitude of the braking torque is 200 per cent, which is greater than that of the starting torque (150 per cent). Hence, in this case, the stresses in the belt drive during stopping would possibly be greater than those occurring during start-up.

4. CASE STUDY NO. 2

The particulars of the conveyor tested are as follows:

Difference between centres:	3 510 m
Height difference between head and tail:	-40 m (downhill)
Drive system:	2 drives on head pulley, 2 drives on tail pulley. All drives are direct on-line squirrel cage motors with fluid couplings
Belt type:	Steel Cord, ST 850, 1 050 mm wide
Take-up:	Load cell/winch
Design tonnage:	1 500 TPH

4.1 Starting the Conveyor

The four drives are step started with time intervals as shown by the theoretical torque build-up in Figure No. 11.

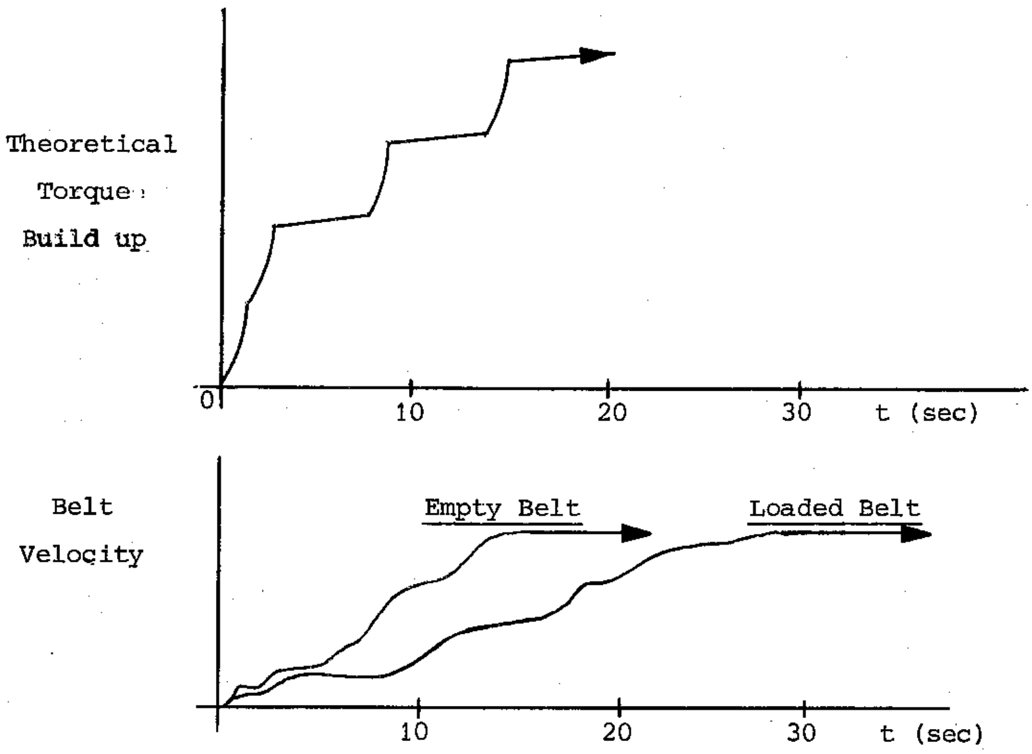


Figure No. 11: Empty and Loaded Starts showing Theoretical Torque Build-up and Resultant Velocity Profile

The loaded belt is started in about 27 seconds, with minor oscillations, except at t = 18 seconds where a slight irregularity is detected.

The empty belt is started in about 13 seconds, with minor oscillations. The fourth drive is only energized after the conveyor has reached full speed. This reduces the accelerating torque magnitude (for the empty belt) and hence extends the starting time.

4.2 Stopping the Conveyor

Figure No. 12 shows the velocity profiles on stopping the conveyor, loaded and empty.

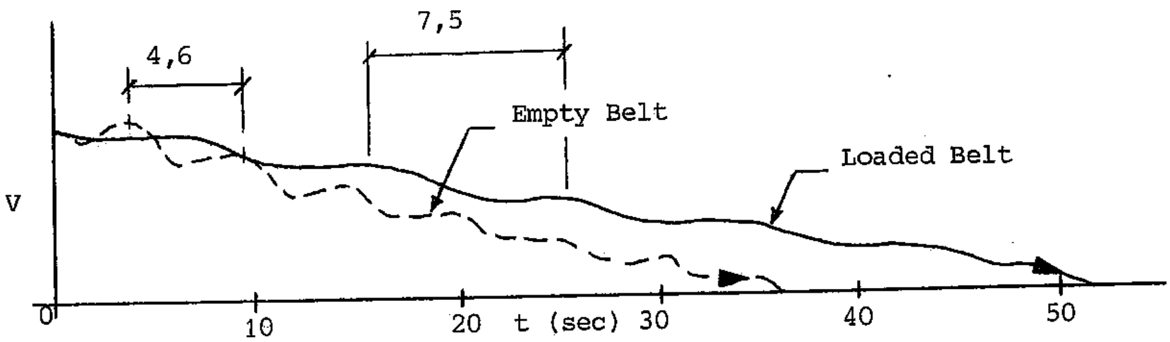


Figure No. 12: Empty and Loaded Belt Velocity Profiles on Stopping the Conveyor

In this case, the oscillations for the empty belt are larger in magnitude and shorter in period than those of the loaded belt.

This is possibly because the de-energizing torque magnitudes for the loaded and empty belt are similar (descending nature of the belt), and because the waves are dampened by the load on the belt.

The stopping times are 36 seconds for the empty belt and 52 seconds for the full belt.

The shockwave speeds (2 x Belt Centres/Wave Period) are:

Empty belt V_{se} = 1 526 m/s

Full belt V_{sf} = 936 m/s

5. CONCLUSIONS

5.1 The occurrence of high belt stresses occurring in a conveyor system is more likely for belts with low shockwave speeds than for belts with high shockwave speeds - the lower the speed is, the longer the waves take to decay.

The shockwave speed for the empty fabric belt (Case 1) is 1 060 m/s while that for the steel cord belt (Case 2) is 1 526 m/s.

5.2 By careful selection of the starting system for the conveyor, and taking into account the acceleration torque rate and magnitude criteria, the possibility of high belt stresses occurring in the belt during starting can be minimised.

5.3 To reduce belt stresses during stopping, a conveyor should be allowed to come to rest freely without external braking. If, however, brakes need to be used, they must be applied gradually or, after a suitable time interval, once the drives have been de-energized.

6. REFERENCES

6.1 Harrison, A: CRITERIA FOR MINIMISING TRANSIENT STRESSES IN CONVEYOR BELTS

Int. Conference on Materials Handling, Beltcon 2, May 1983, South Africa.

6.2 Funke, H: THE DYNAMIC STRESS OF CONVEYOR BELT SYSTEMS WHEN STARTING AND STOPPING

Braunkohle Vol. 26 (1974), No. 3, pp 64-73.

6.3 Funke, H: HYDRODYNAMIC COUPLINGS AS STARTING EQUIPMENT IN BELT CONVEYING

Translation Mashinenmarkt, Wurzburg, 82 (1976) 57