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A refined soft start technique for long conveyor belts

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As we continue to go for long conveyor belts, it is important to pay more attention to the starting and stopping techniques. The longer the belt, the more challenging it becomes to handle its acceleration and deceleration ramps as conveyor belt is a non linear visco-elastic medium, a gigantic rubber band full of load inertia dynamics which can result in destructive consequences if not handled properly. When a fully loaded conveyor belt is started abruptly or with no acceleration control, high acceleration forces induce tension waves that not only adversely affect the belt fabric, belt splices, drive skids, couplings and pulleys but can cause excessive belt take-up movements and spillage of material. Therefore, starting the belt in a manner that such acceleration forces are within safe limits is of a paramount importance.

The rule of the thumb for the starting ramp up time is "30sec per km". This rule generally yields satisfactory results, however, for conveyor lengths exceeding 5~15km, the results of the dynamic belt analysis can be used for determining an acceptable velocity ramp time. Besides catering to the acceptable ramp up time, it is also important to focus on the shape of the velocity curve from zero to 100% range. A linear ramp is not recommended as it may start the belt with a very high "jerk" which could induce a huge tension spike and rip the belt from its weakest link which is the splice section.

Harrison[1] recommended an "S" shaped velocity ramp v/s a sinusoidal shaped acceleration ramp to minimize the dynamic belt tension during starting:

$$v_{(t)} = \frac{\mathbf{V}}{\mathbf{2}}\left(1 - \cos\frac{\pi}{T}t\right),\ 0 \le t \le T \qquad \text{.......(1)}$$

$$a_{(t)} = \frac{\mathbf{V}}{\mathbf{2}}\pi\left(\sin\frac{\pi}{T}t\right) \qquad \text{.......(2)}$$

$$jerk_{(t)} = \frac{V}{2T^2}\pi^2\left(\cos\frac{\pi}{T}t\right) \qquad \text{.......(3)}$$

where:

- V - designed running speed of the belt
- $v_{(t)}$ - belt velocity as a function of time
- T - time to accelerate the stationery belt to speed V
- a - acceleration
- t - time

As per equations-1~3, as velocity forms an "S" shaped curve from 0 to 100%, the acceleration curve follows a sinusoidal path. The jerk (first derivative of acceleration) curve is continuous, except at the beginning and end of the acceleration ramp. This relationship is shown in Figure-1.

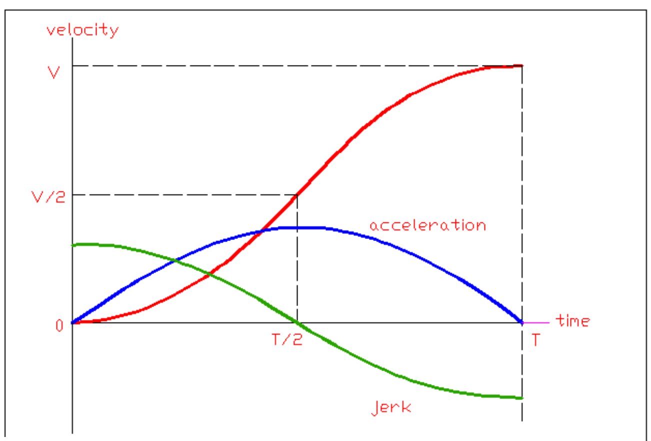


Figure 1: "S" velocity curve with sinusoidal acceleration profile

As long as the velocity curve is "S" shaped, the results are very satisfactory for minimizing peak tension transients during belt start. As per Nordell[2], the "S" band velocity curve reduces belt peak stress by 15%, peak motor torque demand by 17% and besides reducing the potential drive pulley slip on belt, the most important of all, it reduces jerk and belt tensile wave impulse on all non-drive pulleys and structure.

Several control system engineers, while tuning starting ramps, introduce an additional **dwell** period in the velocity ramp profile, as shown in Figure-2. The dwell period of 10~20 sec at around 5% belt speed allows the initial belt slack to be pulled out, and all the conveyor elements attain a running condition at very low torque and speed before the belt is accelerated to full speed with higher torque values. This eliminates overstressing of the belt.

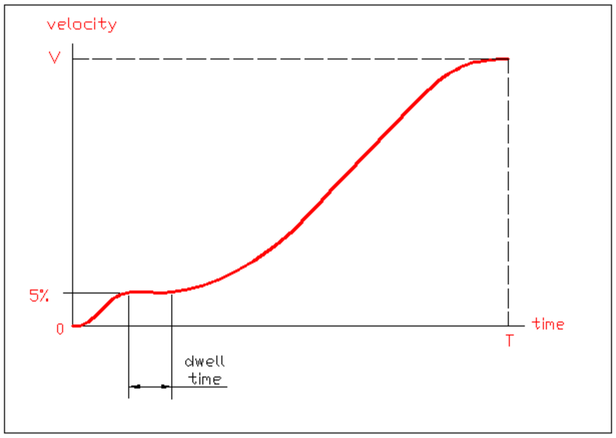


Figure 2: "S" curve velocity ramp profile with 'dwell' time at 5% velocity.

With time and experience, it has been found that if the tuning of the conveyor controller; the proportional & integral settings are not done correctly, during dwell time of 10 ~ 20s, the belt is likely to go into uncontrollable oscillations, inducing tension waves that could be detrimental to conveyor structure.

2T+0.8T Algorithm: The new technique, discussed in this paper, skips the dwell time completely. Considering total "S" ramp curve time in 100 counts, the new algorithm initially starts the belt by setting the ramp time to 2T for the first 10 counts, and then switch back to 0.8T sec for the remaining 90 counts. This way, the belt moves continuously, without stalling or dwell anywhere during the motion. The first 10 counts period at 2T ramp time allows the initial belt slack to be pulled out and all the conveyor elements, such as tail pulley, idlers, back stop positioning etc. attain a running condition. Tuning of the PID gets simplified, once the P and I parameters are determined, all through the actual speed curve (feedback) follows closely the desired set-point "S" curve from zero to full speed.

The equations as per new algorithm are as following:

$$v_{(t)} = \begin{cases} \frac{V}{2}\left(1-\cos\frac{\pi}{T}t\right), 0 \le t \le 0.2T \\ \frac{V-V_{(0.2T)}}{2}\left((1-\cos\frac{\pi}{0.8T}(t-0.2T)) + V_{(0.2T)}\right), 0.2T \le t \le T \end{cases} \tag{4}$$

$$a_{(t)} = \begin{cases} \frac{V}{2T}\pi\left(\sin\frac{\pi}{T}t\right), 0 \le t \le 0.2T \\ \frac{V-V_{(0.2T)}}{2(0.8T)}\pi\left(\sin\frac{\pi}{0.8T}(t-0.2T)\right), 0.2T \le t \le T \end{cases} \tag{5}$$

$$\text{jerk}_{(t)} = \begin{cases} \frac{V}{2T^2}\pi^2\left(\cos\frac{\pi}{T}t\right), & 0 \le t \le 0.2T \\ \frac{V - V_{(0.2T)}}{2(0.8T)^2}\pi^2\left(\cos\frac{\pi}{0.8T}(t - 0.2T)\right), & 0.2T \le t \le T \end{cases} \quad (6)$$

Example: Suppose the velocity ramp up time of a conveyor is 100seconds (T= 100s). The control algorithm shall plot the complete “S” velocity profile in 100 counts. As shown in Fig-3, the first 10 counts will plot $\mathbf{S}_{T=200}$ curve in 20 seconds and the speed set point will attain 2.5% (Each count duration is 2s). At the 11th count, the algorithm switches the path to an $\mathbf{S}_{T=80}$ curve which gets plotted in the remaining 90 counts (Each count duration is now 80/90 = 0.888s).

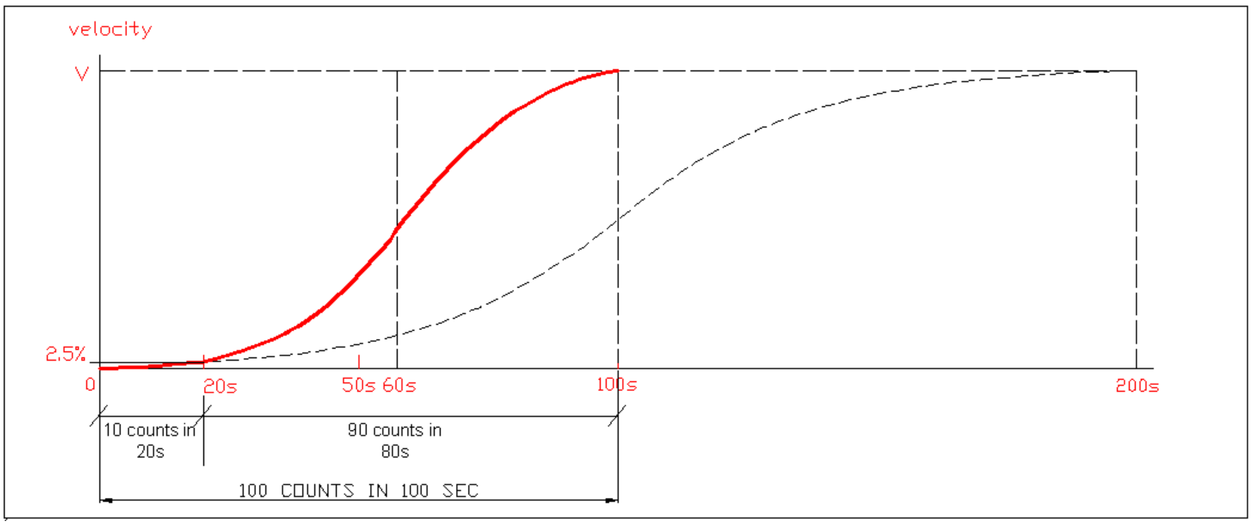


Figure 3: A modified version of the S ramp velocity curve

Case Study: The new soft start technique was tested on an 8km long conveyor in China (Fig-4). Basic conveyor parameters:

Conveyor	8000m long, Nett Lift: -26.5m
Capacity	1600tph Limestone crushed-80mm, density 1450kg/m^3
Belt	Strength-2500 N/mm, width – 1200mm, thickness- 21.2mm, belt speed – 3.5m/s
Drives	3 x 560kW Head + 2 x 560kW Tripper
Take up	Hydraulic Winch rated 200kN at full load
	Starting/Running tension, whether fully loaded or empty belt – 70kN

As per dynamic analysis, the belt starting ramp time is 120s, the tripper located 3.5km from tail, maximum tension of 374kN (fully loaded) at the tripper and 371kN at the head pulley provides a good tension share balance between head and tripper drives as well as nominal 1.2 safety factor. And to attain an even load share between head and tripper drives (54% head – 46% tripper), the target tension range of the tension load cell arrangement for the tripper is 200kN at starting and 150kN at running.

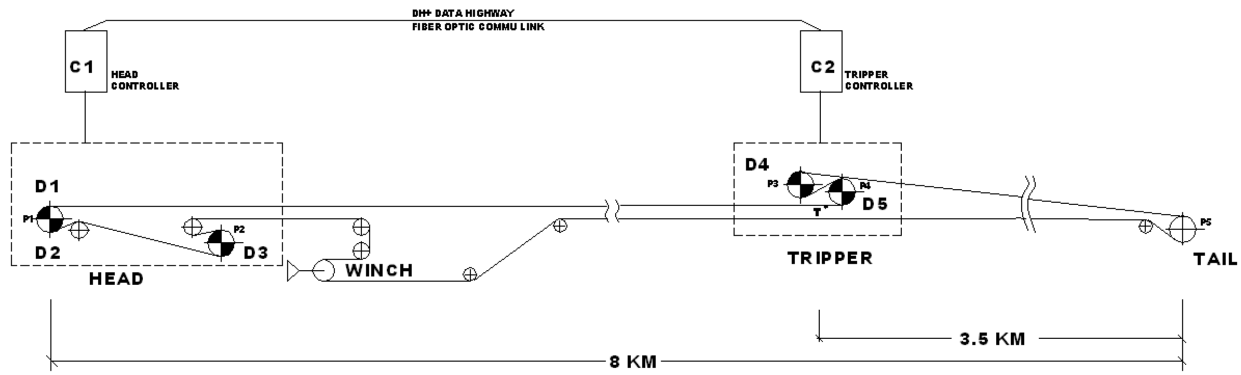


Figure 4: Yulong Cement, China - 8kM long conveyor with 3 x 560kW drives at Head station and 2 x 560kW drives at the tripper station, commissioned in 2003.

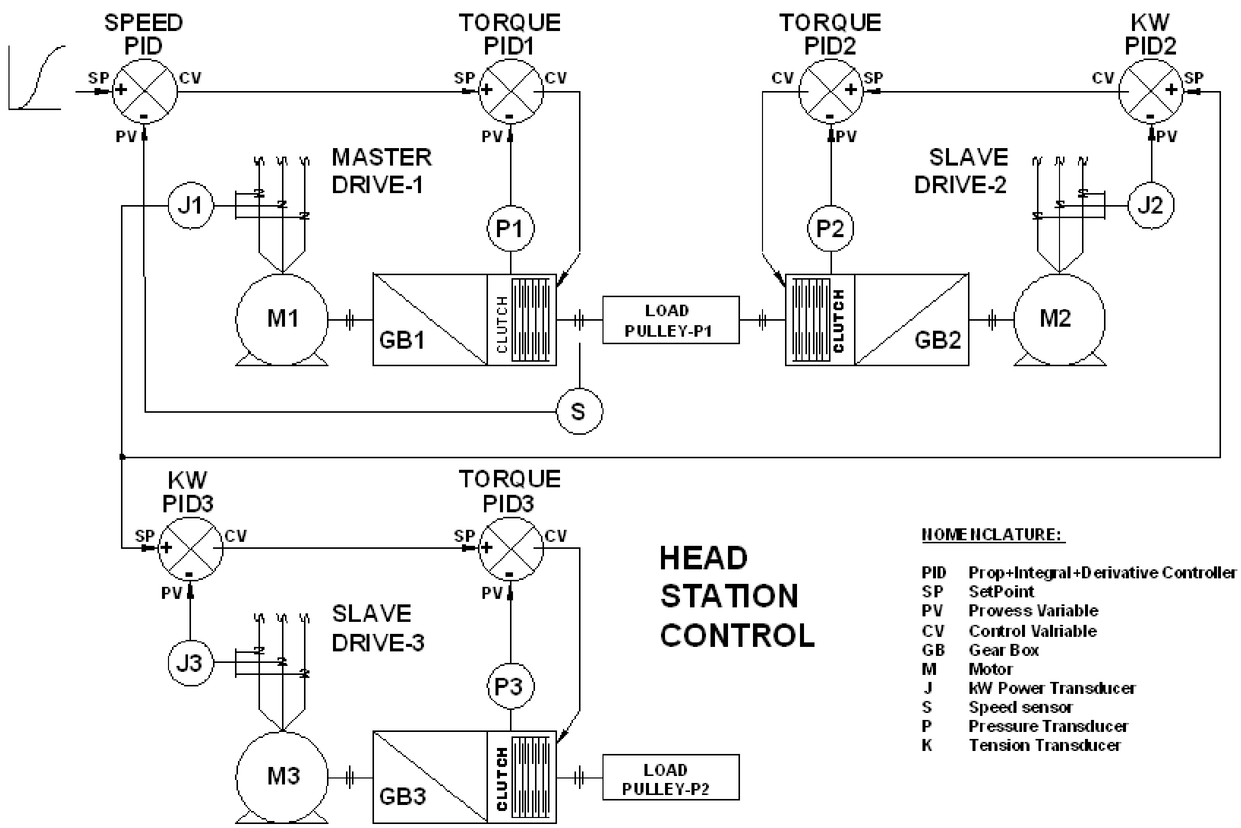


Figure 5a: Yulong Cement, China - 8kM long conveyor. Head station drive arrangement and PID control scheme.

The general arrangement of the 3 drives at the head station is depicted in Figure-5a; each drive skid comprise a standard 3phase,560kW/50Hz/1485rpm Industrial AC motor coupled to a gearbox which has a wet clutch on its output shaft side which is further coupled to the load pulley. In a de-clutched mode, initially the drive motor starts on no load and thereafter, as the wet clutch is engaged gradually by applying a controlled hydraulic pressure from the drive PLC controller, the motor torque multiplied by the gear box ratio, gets gradually transferred to the pulley load via the wet clutch. The drive controller at Head Station is programmed with a set of following PID (Proportional + Integral +Derivative) blocks:

- Speed PID control loop: This takes the belt speed signal from a speed sensor located at the output shaft of the drive as the process variable (P_v) signal, the control variable (C_v) signal is cascaded to the Pressure control PID loop of the Master drive. The speed set point signal is written by the PLC algorithm to control the conveyor belt speed.
- Pressure/Torque PID control loop: This close control loop regulates hydraulic pressure on the piston of the wet clutch. Indirectly, it regulates the transfer of motor torque very precisely to the load. The set point of this PID is cascaded with an outer control loop which could be a SPEED PID or kW PID loop.
- kW PID control loop: The kW close PID loop is active for the slave drives only. As shown in Fig-5, the kW loading signal of the Master drive motor is cascaded to the slave drives kW PID loops. This way, whichever way the master drive motor gets loaded, the slave drives follow to ensure load share within ±2%.

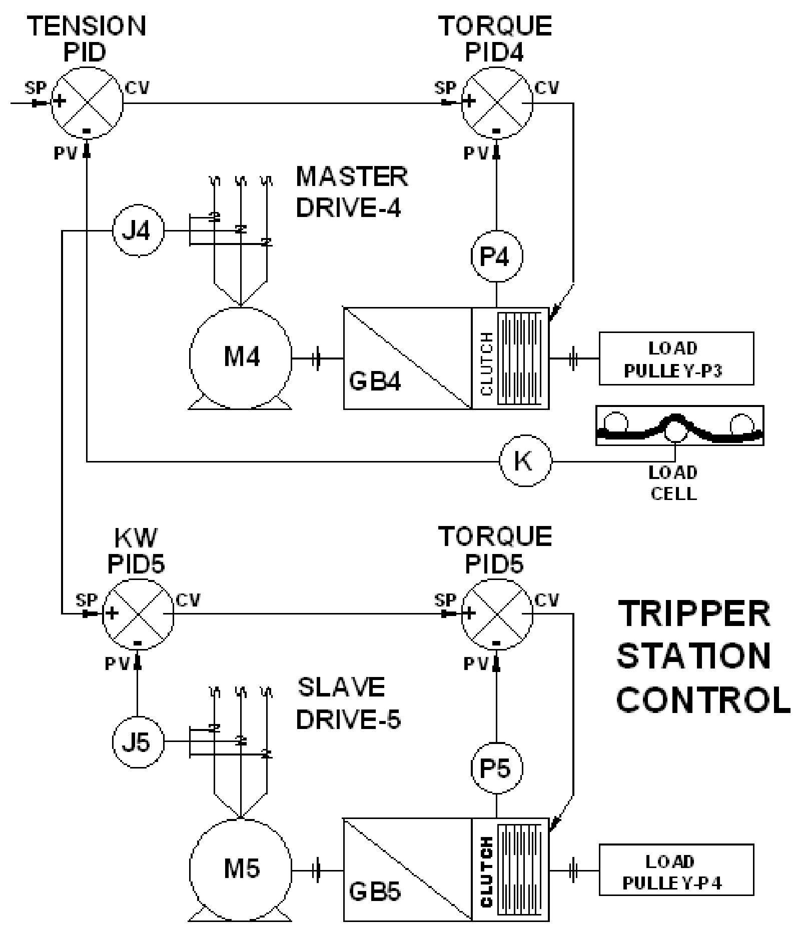


Figure 5b: Yulong Cement, China - 8kM long conveyor. Tripper station drive arrangement and PID control scheme.

The general arrangement of 2 drives at the Tripper station is depicted in Figure-5b.The drive controller at the Tripper Station is programmed with a set of following PID (Proportional + Integral +Derivative) blocks:

- <u>Tension PID control loop:</u> This takes the Tension signal from a set of load cell sensors mounted in a tension measuring frame assembly, the control variable (C_v) signal is cascaded to the Pressure control PID loop of the Master drive. The tension set point signal is written by the PLC algorithm to control the belt tension.
- <u>Pressure/Torque & kW PID loops:</u> These control loops are configured as slaves and operate in similar manner as explained above for Head drives.

The 8km long conveyor was commissioned in 2003 with a ramp up time of 120s. However, in November of 2011, the ramp time was increased to 150s on the standard old 'S' curve program, and dwell time kept to 20s. The speed loop PID parameters were tuned to P=120 (Gain), I =8 repeats/sec (Integral time) and D=0 (derivative action). It was worthwhile to observe (See Figure-6) , when belt started to move, a small 'blip' in velocity profile (red color) shows that the initial 'jerk' caused the carriage of the winch to travel to & fro. This may have induced aperiodic tension waves in the return belt path and during the dwell period, the tension at the tripper station went oscillatory. And all through the ramp, the actual belt velocity ramp could not follow closely the speed set point.

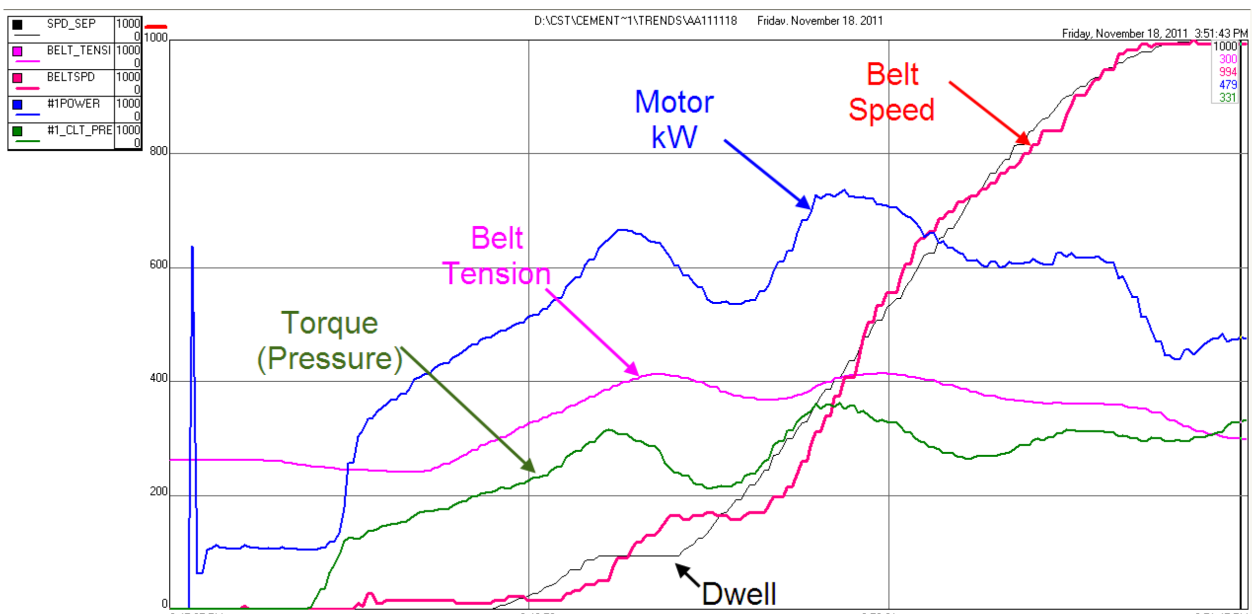


Figure 6: Yulong Cement, China - 8kM long conveyor, 150s belt ramp up with 20s dwell time.

However, when the belt was restarted with the same PID settings and the 2T+0.8T algorithms, a very smooth velocity ramp was recorded (Fig-7). The belt crept initially for 20s on a 2T ramp curve and then accelerated on the 0.8T ramp curve, the winch stayed stable and the velocity curve (red color) followed the speed set point very closely. Tensions were stable and load share at the head station as well Tripper drive station was well within ±2%.

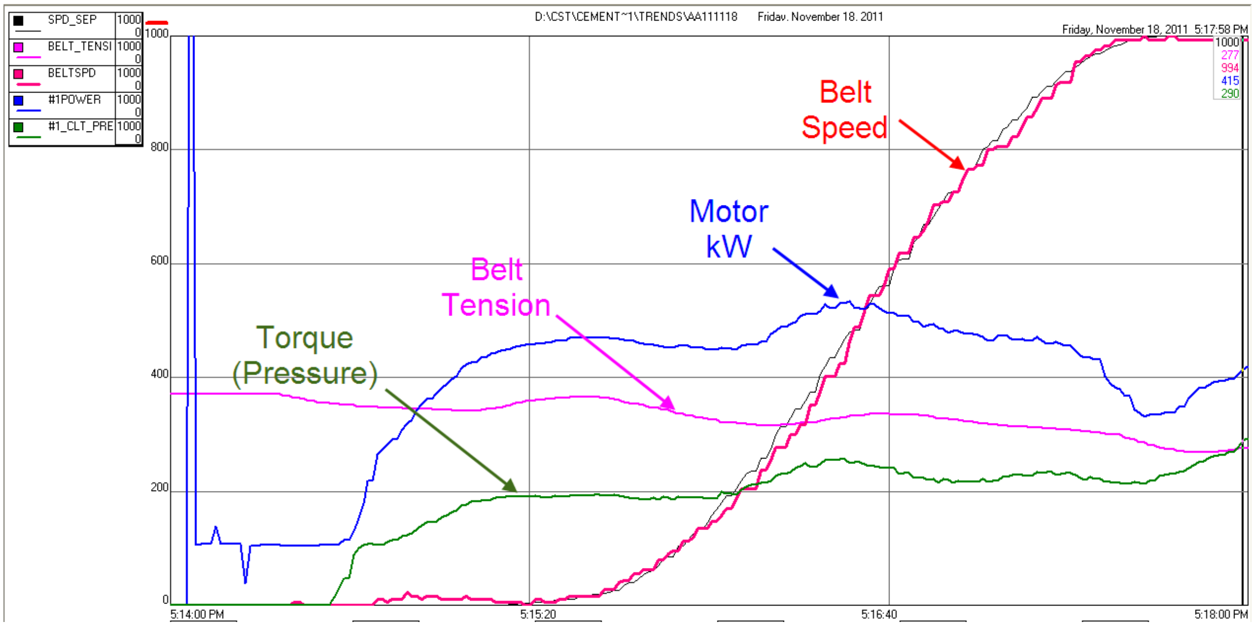
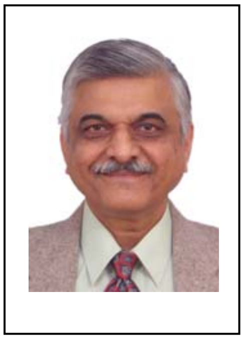


Figure 7: Yulong Cement, China - 8kM long conveyor, 150s belt ramp up with 2T+0.8T soft start algorithm.

Conclusion: It has been observed that for long conveyors, a very gentle creep start and then ramp up gradually without stalling anywhere results into a very smooth start up. The new technique 2T+0.8T has shown far better results. Tuning of PID control loops is simplified and commissioning of the conveyor gets done much faster.

REFERENCES:

1. Harrison, A: "Criteria for minimizing transient stress in conveyor belts". Int'l Materials Handling Conf., Johannesburg, SA May 1983.
2. Nordell, L.K: "Improved High Capacity Conveyor Designs". American Mining Conf., San Francisco, USA, 1989



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