

Conveyor Tension and Take-Up Systems

By

Ian Plunkett

Technical Director

Iptron Technology cc

Tuesday, July 08, 2014

Contents

1. Pre-amble	3
2. Conveyor Belt Running	3
3. Conveyor Dynamics and Acceleration.....	4
4. Types of Conveyor Belt	4
5. Conveyor Starting & Stopping.....	5
1.1. Controlled Acceleration of Conveyors.....	5
1.2. Controlling running tension of conveyors	5
1.3. Tension variations during belt stopping.....	6
6. The need for Take-Up Tension.....	6
7. Conveyor Take-Up Devices	6
1.4. Gravity/Counterbalance Take-Up Devices.....	7
8. The Role of Take-Up Winches.....	7
1.5. Take-Up Winches	8
1.6. Fixed Speed Winches.....	8
1.7. Variable Speed Winches	9
9. Running the Conveyor	9
9.1. Acceleration Control	10
10. Conveyors with Variable Acceleration Control.....	10
11. Conveyors with Delayed Fill Fluid Couplings	11
12. Control Philosophy for Take-Up Winch Operation	11
13. Overtension devices for winches.....	12
13.1. Brake Band on Planetary Gear	12
13.2. Multi Disk on Planetary Gear	12
13.3. Transient Shock Absorbtion	12
14. Safety Policy, Stored Energy, Belt Stopping and Aborted Starts	12
15. References:	13

1. PRE-AMBLE

A conveyor belt is a very efficient machine for conveying bulk material over any distance. Optimizing the design of a conveyor belt for throughput, distance, speed and reliability versus cost is an ongoing quest. Tension in a conveyor belt is fundamental to its very operation in terms of supporting the load between rollers and enabling the drive to impart motion to it. For a conveyor on the verge of slipping, there is a direct ratio between T1, the traction force imparted to the Conveyor and T2, the Take-Up Tension, of a Conveyor Belt. This ratio is of the order of 10 for a single drive pulley. This is defined by the formula:

$$T1/T2 = e^{\mu\alpha}$$

Where:

T1 = Incoming Tension

T2 = Take-Up Tension

e = 2.718 (natural logarithm)

μ = Coefficient of Friction on the Pulley

α = Wrap Angle of the Belt on the Pulley in Radians

There are dozens of publications describing this so we take it that you are generally familiar with this subject. (See end for references)

2. CONVEYOR BELT RUNNING

While the Conveyor is running all tension variations are due to start-up acceleration, stopping/deceleration and change in the load. Some belts have multiple loading points and can have rapid changes in tension. Controlling the tension during this period is a non event and this is what would-be 'tension control designers' tend to focus on; very easy. Conveyor Tension Control is primarily about start-up and stopping; it is about handling the tension transient waves generated during starting and stopping. The worst transients result from sudden loss of power particularly at the peak of acceleration; this is the sudden release of all the stored energy of belt stretch; it resonates up and down the conveyor colliding at each end like a soccer ball bouncing against a wall. This energy is eventually dissipated in the friction of the idlers and the movement of the loaded material. On start-up, the very motion of the belt causes transient waves; all and any change in velocity, is acceleration or deceleration, is associated with transient

waves. If the acceleration rate is constant, there will a continuous imperceptible wave exhibited by a progressively decreasing tension all the way down the belt.

3. CONVEYOR DYNAMICS AND ACCELERATION

A conveyor belt behaves as a classical Transmission Line. It takes time to accelerate the belt up to speed and also for tension changes to propagate along the belt. The speed of propagation depends on the conveyor elasticity, the belt's construction and the material loaded on it. Thus every conveyor belt has a time constant that varies accordingly.

The Velocity of Longitudinal Tension Wave propagation in a conveyor belt depends on the conveyed material. The approximate propagation Velocities for loaded belts are:

- a) Fabric Belt +/- 1000 meters per second
- b) Steel Cord Belt +/- 3000 meters per second

4. TYPES OF CONVEYOR BELT

Conveyor Belts are basically either Fabric or Steel Cord. From a movement point of view, the drive requirements are little different. However there is an order of difference between the elasticity of the two types; Fabric Belts stretch 10 times more than Steel Core Belts. The Steel Cord belt requires the same tension but the required Take-Up speed is only 10% of that for a fabric belt. This means that the Gravity/Counterbalance Tower would need to be e.g. 5 meters instead of 50 meters.

The use of winches for tension adjustment of conveyors is an obvious application of a Haulage Winch. However the needs of conveyors vary in respect of:

- a) Length
- b) Tension
- c) Width
- d) Load
- e) Elevation
- f) Elasticity (Fabric or Steel Cord)
- g) Main Drive Configuration
- h) Acceleration Control
- i) Belt Stop Dynamics
- j) Response time

5. CONVEYOR STARTING & STOPPING

The common method of starting short to medium length conveyors is a torque limiting coupling. Common among these are the Delayed-Fill Fluid Coupling and the Magnetic/Eddy Current Coupling. The difference in speeds between the input shaft and output shafts multiplied by the transmitted torque determines the rate of energy dissipation in the coupling. This action will cause a temperature rise in the coupling and this imposes a time/temperature limit for acceleration. Characteristically a conveyor belt with a Delayed-Fill Fluid Coupling will experience a high acceleration rate and a high rate of generation of slack which must be accommodated by the Take-Up System. Failure to accommodate the slack will result in drive pulley slip, causing additional Tension transients to be generated in the belt as well as possible damage to the drive roller lagging and the conveyor's covers.

The stopping of a conveyor belt often occurs due to an Emergency Trip or Power failure. As a result of the sudden loss of drive power, the conveyor Take-Up system is suddenly exposed to a sharp Tension Transient which often exceeds the Start-Up transients in magnitude. A Gravity Tower Mass will lift and store the transient energy and then send it right back out again.

As with all machines, a higher power is required to accelerate the belt than to maintain its speed. The required Take-Up Tension (T_2) is directly proportional to the applied acceleration force (T_1). Thus the Starting tension must be increased for start-up.

1.1. CONTROLLED ACCELERATION OF CONVEYORS

By controlling the acceleration rate of a conveyor by means of an AC Variable Drive or a Controlled-Fill Coupling (with Radiator), the start-up time can be increased to dramatically reduce the tension transients. This type of system enables the conveyor to be accelerated at a predictable and much more comfortable rate. Long Conveyor Belts can only be started with a controlled acceleration.

1.2. CONTROLLING RUNNING TENSION OF CONVEYORS

While the conveyor is running, tension does not usually change rapidly. Controlling tension during running is extremely easy and a slow Take-Up Winch will do this very easily. It is this condition that is so deceptive of Conveyor Tension Control.

The exception to this is where multiple loading points are used on trunk conveyors where simultaneous loading can and does occur.

1.3. TENSION VARIATIONS DURING BELT STOPPING

When a conveyor is stopped, it is often as a result of a 'Safety' or 'Emergency' Trip. This always causes Tension Transients even though it is possible to decelerate the conveyor to a standstill. Safety protocols often prescribe that the power is cut immediately. The worst case scenario is when a power trip occurs at the peak of acceleration.

6. THE NEED FOR TAKE-UP TENSION

The conditions of operation of a conveyor belt vary continuously with start-up, with running with varying load and stopping. It is crucial that the Take-Up Tension on a Conveyor Belt is adequate for all the varying conditions. The minimum required tension is directly proportional to the Conveyor Drive Load. When the belt is empty, a low tension would suffice. When the belt is full a higher tension is required. During Start-Up an even higher tension is required. Following an aborted start, there will be tension transients resonating up and down the belt. Ideally the Take-Up Tension Controller and the Main Drive Controller should interact to provide the optimum tension for all conditions.

There is hardly any machine in this world whose performance is not improved by automation and control. Only a controlled winch can achieve full and optimal control.

7. CONVEYOR TAKE-UP DEVICES

In searching for Conveyor Take-Up Actuation, there are a variety of devices to choose from:

- a) Gravity Tower/Counterweight
- b) Hydraulic
- c) Screw jack
- d) Manual Winch
- e) Air Winches
- f) Electric Winch
- g) Constant Tension Winches
 - a. Magnetic Slip Clutch

- b. Torque Motor
- h) Controllable Tension Winches
 - a. AC Variable Drive Winch

Every Conveyor is designed to handle a specific load. However, increased capacity is Tension Take-Up is often the limiting factor.

1.4. GRAVITY/COUNTERBALANCE TAKE-UP DEVICES

Gravity/Counterweight Towers will always be the starting/reference point in most designs because they are the easiest to work out. Most Conveyor Design Programs cater solely for Gravity Towers. However gravity towers generally involve quite a number of rope sheaves. Note that a new Steel Rope on a new Sheave will have a typical friction of 1½% of the rope tension; this is made up of two-components, firstly the Sheave Bearing's low friction but also important the friction in flexing the rope into and out of the sheave especially in old unlubricated systems.

Performance of Gravity/Counterbalance Towers

<u>Advantages</u>	<u>Disadvantages</u>
Easily understood.	Always well above starting tension.
High Speed Response.	Imprecise control due to friction.
Not affected by Loss of Power.	Near impossibility to diagnose friction
Purely mechanical.	Dynamically 'unterminated'.
Damping by inherent friction.	High maintenance .
	Errors through entire rope transport

Clearly Gravity Towers are not all they are cracked up to be.

8. THE ROLE OF TAKE-UP WINCHES

Electric Winches afford the possibility of a simple design. Compared with Gravity Towers, Take-Up Winches require fewer sheaves. The method of control of the winch determines the scope of its application.

Fitting a single Sheave to a Take-Up trolley enables a Tension Transducer (Load Cell) to be fitted to the 'dead end' to provide an accurate measurement of the Conveyor Tension (assuming that the Take-Up Trolley's friction is very low) and will have an accuracy of better than +/-5%. Only the ropes in-line with the trolley

that have sheaves between them can cause a measurement error. All other sheaves have no effect on the tension measurement but do directly affect the loading on the winch.

Controlling the tension of a conveyor belt looks so simple but in reality is a deceptively complex task aggravated by the fact that a slow winch is needed during running and a fast winch is needed for Starting and Stopping. This is particularly demanding for Conveyors using Fluid Couplings where the high acceleration rate causes belt slack to be generated faster than the winch can handle. No fixed-speed winch can ever satisfy this requirement properly.

The greatest demand on the Take-Up Winch occurs during start-up and stopping when the winch needs to be able to follow the rapid tension transients. This need clearly suits the use of AC Variable Drive for Tension Control of ALL conveyor belts. Using AC Variable Drive on a Take-Up Winch can solve all the shortcomings of a fixed speed winch as well as of a gravity tower:

- 1) Can provide both slow and fast tension adjustment
- 2) Elimination of 'Starts per Hour' on motor size.
- 3) Full PID can be applied
- 4) Optimal belt tension under all conditions.
- 5) Tension can be changed at will to suit different load conditions.

A fixed speed winch of 6 meters per minute is best suited to a fabric belt of 500 meters or a Steel Cord Belt of 5000 meters.

1.5. TAKE-UP WINCHES

Historically Conveyor Take-Up Winches derive from Haulage Winches. For safety reasons, their speed limited to between 5 and 6 meters per minute. A haulage winch is intended for construction and other similar uses where speed would be dangerous. There is a huge gap between Take-Up Winches suited to for short conveyors and those suited to long conveyors.

1.6. FIXED SPEED WINCHES

No fixed speed winch can match the performance of a Gravity Tower. No matter what the size of the conveyor belt, the dynamics are the same. A fast winch is needed for start-up and a slow winch for running. Because of this the start-up tension will need to be a minimum of 150% of running tension. The requirement that the winch should be able to match the slack generated during acceleration cannot be met in practice because a fast winch would require a much larger motor

and a different gearbox. For a fixed-speed winch a faster winch would not be able to control the running speed tension.

Fixed Speed Winches are controlled by Forward/Reverse Contactors. The size of the motor determines the permissible frequency of motor starts; the larger the motor size, the lower is the number of permissible starts per hour. Winch size for fixed speed winches is thus limited. Although the duty cycle of Forward/Reverse controlled Winches is very low and the motor is only loaded during tension increase, Motor burn-out of winches is common for hard-working or malfunctioning systems.

1.7. VARIABLE SPEED WINCHES

The use of winches for automatic tension control is an obvious development but the bottom line is that no fixed speed winch can ever compete with a gravity tower. Without the automatic variation of speed to match the demand, Fixed Speed Winches are forever limited in usefulness to the shorter belts. To render a Fixed Speed Winch workable, the conveyor's tension must be raised by as much as 50%. To perform properly, a Take-Up Winch needs to emulate the behaviour of a Gravity Tower.

Operationally, the conveyor spends almost 100% of its time at running speed requiring a slow winch for adjustment; it is the Start-Up and Stopping of the Belt that impose the greatest demand on the winch. A fixed speed winch is usually suited to be able to control the running tension and it can do this very easily. However the winch has a very hard time keeping up with a Fluid Coupling drive system. Two-Speed Winches with a 3:1 ratio have been used with some success but maintenance is high.

9. RUNNING THE CONVEYOR

Newton's First Law of Motion ' $F = ma$ ' tells us how much force is required to accelerate a mass up to a given velocity. Every moving part of a conveyor system contributes to the inertia as well as the 'rolling' friction of the conveyor belt. Adding to this is the energy input (or output) in raising (or lowering) the conveyor's load from one end to the other. The driving force required to accelerate the conveyor belt is therefore higher during acceleration than during normal running. The higher the acceleration required, the higher the starting force required and the quicker the belt will reach full speed. The method of acceleration control of the conveyor drive determines the amount of slack generated and thus the required winch speed during start-up.

Short conveyors may be simply Direct-on-Line and while tension setting is always important, automatic tension control is often not required.

9.1. ACCELERATION CONTROL

9.1.1. Fixed Acceleration of Conveyor Belts

9.1.1.1. Fluid Couplings

Medium (fabric) conveyor belts from 100 metres to 750 metres usually use Delayed-Fill Hydraulic Couplings for acceleration control. Some belts up to 1500 metres also use this method but the longer the belts the more dramatic the tension transients become. Fluid Couplings act like a slipping clutch and generate a lot of heat. Overheating causes a thermal plug to release the hydraulic oil and thus have a limited capacity. The conveyor start-up must be completed before the oil temperature gets too high. With longer conveyor belts, the acceleration is proportionately more aggressive. Fluid Couplings are passive devices. This is the limitation of this type of acceleration control.

9.1.1.2. Magnetic Couplings

Magnetic couplings have a large copper disc located rotating within powerful magnets. Eddy currents cause the copper disc to heat up. Operation is similar to fluid couplings.

9.1.2. Adjustable Acceleration of Conveyor Belts

9.1.2.1. Adjustable Fluid Couplings

The oil fill of these couplings can be varied to control the acceleration but they also have an external cooling system. This type of coupling is passive, and the heat dissipated is proportional to the speed difference between the input and output shafts and the torque. They can be run continually at any speed.

9.1.2.2. AC Variable Conveyor Drive

AC Variable Drives are becoming the norm in conveyor acceleration control because of their reliability, incredible performance and decreasing price. Cooling is still required but nowhere near that of hydraulic couplings. If the conveyor is required to run at very low speed, forced cooling of the motors is necessary.

10. CONVEYORS WITH VARIABLE ACCELERATION CONTROL

When the acceleration of a conveyor is controlled by a continuously variable system, the acceleration rate can be controlled so that the slack generated during start-up is kept low enough for a Fixed Speed Take-Up Winch to keep up with it. In this situation, the starting tension can be correctly set. If the conveyor has controlled deceleration to a stop, there will be no large tension transients generated. If the power is lost during acceleration, (particularly at peak acceleration), there will be massive tension transients generated. If the conveyor belt is stopped by cutting the AC Variable Drive there will also be transients generated.

11. CONVEYORS WITH DELAYED FILL FLUID COUPLINGS

The majority of short underground conveyors use Delayed-Fill Fluid Couplings which provide a 'Soft Start' for a conveyor. In doing so, energy is absorbed by the coupling at a rate proportional to the speed differential.

12. CONTROL PHILOSOPHY FOR TAKE-UP WINCH OPERATION

The control philosophy for the start-up, running and stopping of a conveyor belt is not well defined. The following sequence is required for the integration of any Take-Up Winch into a conveyor control system:

- 1) Front Belt Running.
- 2) Safety Devices Clear.
- 3) Run sequence initiated.
- 4) Pre-Start Warning Stage 1 - e.g. 30 seconds.
- 5) Run Request to Tension Control Panel.
- 6) Starting tension selected, Tension immediately increased to this level.
- 7) Pre-Start Warning Stage 2 - Until Starting Tension has been achieved.
- 8) Run-Ready to main Control.
- 9) Conveyor Drive started.
- 10) Tension Control responds rapidly to Tension Deviations.
- 11) Conveyor reaches full speed.
- 12) Tension Controller response changes to slow.

The following sequence is required for stopping the belt:

- 1) Stop command initiated either because of 'Stop' Command, Front Belt stoppage or Emergency Stop or loss of power.
- 2) Tension Control System (If active) senses the termination of the 'Run' Command and changes the system control level to "Stationary". Immediate response enabled.

3) Conveyor tension is controlled to 'Stationary' level.

From a control point of view it is always preferable to do a controlled stop. This is of course not possible if the acceleration (or Deceleration) rate cannot be controlled. Also it is preferable that the Take-Up Winch remains active at least until after the conveyor has completely stopped and stabilised. This characteristic should be the norm where the customer insists that the Take-Up Winch be disabled as soon as the belt 'Run' is terminated.

13. OVERTENSION DEVICES FOR WINCHES

13.1. BRAKE BAND ON PLANETARY GEAR

Winches with Planetary Gears use this rugged design as the last reduction stage of the Winch drive. The Planetary gears are normally stationary but the addition of a slip clutch to this affords easy and relatively direct access to the Winch Drum where an additional larger (external) brake disk or drum can be fitted. Common practice is to have a double-wrap Brake Band with a cantilevered counterweight pivoted to apply tension to the Band. However the pivots need to have needle rollers to ensure any accuracy.

The type and location of slip clutch depends on the mechanical configuration of the winch. Of necessity the slip clutch must operate without power. Building a slip clutch to operate precisely at a particular level is a major challenge. There are multi disc clutches with adjustable spring pressure. Note that any such device will must use the 'static friction' value.

13.2. MULTI DISK ON PLANETARY GEAR

A Multi-Disk Brake fitted to the Planetary Gear Shaft would perform the same operation as the brake band above. This would be better protected from the environment and eliminates the high friction Cantilever.

13.3. TRANSIENT SHOCK ABSORBTION

A hydraulic shock absorber system with a roller on it could be used to absorb transients generated during stopping and aborted starts. Some form of spring would be required and this could be mechanical or hydro-pneumatic.

14. SAFETY POLICY, STORED ENERGY, BELT STOPPING AND ABORTED STARTS

From a safety point of view, stopping the conveyor is a very serious issue. The stored energy has become a safety monster. The requirement is not only to stop the belt safely and without damage to equipment, but there is a call for all stored energy to be easily dissipated under manual control with the power 'OFF'. This is all in the interests of maximizing production.

The prime problem with all long conveyor belts is to get the belt started and up-to-speed. However there is another side to this 'coin'. Once start-up has been satisfactorily achieved, the next problem is to stop the belt.

This is not so easy because there is 'Stored Elastic Energy' unequally distributed in the belt. When the Drive Power is cut in an emergency stop, the prime concerns are that the belt and the structure can tolerate without damage the resulting tension transient waves oscillating from end to end on both sides of the belt. The energy is ultimately dissipated in the movement of the belt and load material over the Idlers. The most damaging kind of stoppage is the aborted start; i.e. during the peak of acceleration. This becomes the principal limiting factor in raising production level.

This has to be dissipated safely not just in terms of personnel but also in terms of avoiding damage to the belt and the structure. This is often aggravated by the Safety Policy which is usually not concurrent with the Control Philosophy. A controlled stop in deference to an emergency stop is a different thing. This is because the 'Emergency Stop' is the norm.

Paramount in this is the requirement that a slip clutch must operate instantly. This precludes putting the slip clutch at the motor end of the gearbox because of the high inertia. Varying methods have been applied to this problem:-

- 1) Slip Clutch on Winch.
- 2) Hydraulic Shock Absorber.

15. REFERENCES:

- 1) Selection of Conveyor Pulley by Sandvik Conveyor Components.
- 2) Design Fundamentals by Phoenix Conveyor Belt Systems.
- 3) Technical Information; Project and design Criteria for belt conveyors. Pages 9-66 by Rulmeca

Printed: Thursday, July 17, 2014