JASDIP Pty Ltd
ABN 50 070 871 313
Innovative Control Systems, Design and Solutions

STARTING CONVEYORS USING VARIABLE TORQUE DRIVE TRANSMISSIONS

WET CLUTCHES AND FLUID DRIVES

STARTING CONVEYORS USING VARIABLE TORQUE

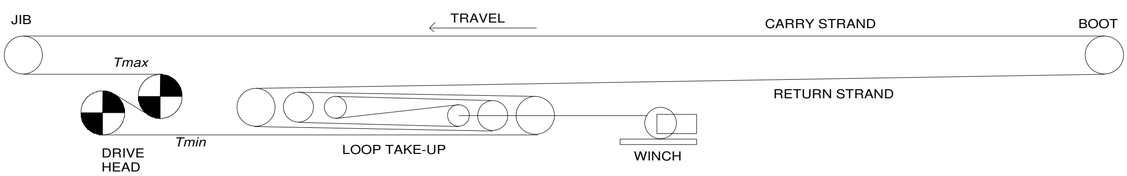
This document describes the philosophy and the necessary components in a control system for variable torque wet clutches and fluid couplings for conveyor starts.

There are two wet clutches currently available in Australia for starting conveyors. These are BOSSes from Nepean Conveyors and CSTs from Dodge/Reliance. Variable Scoop Fluid Couplings are supplied by Voith & David Brown Gears. Although different in design and technology, their control principles are similar enough to be treated as the same.

The purpose of using variable torque devices, to start a conveyor, is to provide a smooth starting ramp that places minimum strain on clips, splices, belt carcass and drive transmission. Wet clutches give very accurate control of the transmitted torque at low conveyor speeds. It is critical on long conveyors (>2kM) to **slowly** accelerate a conveyor up to 10% speed so as to fully stretch the conveyor smoothly and evenly before further acceleration. This reduces the tension waves which may break belting or overstress mechanical components.

STRETCHING AN ELASTIC BAND TO ITS LIMIT

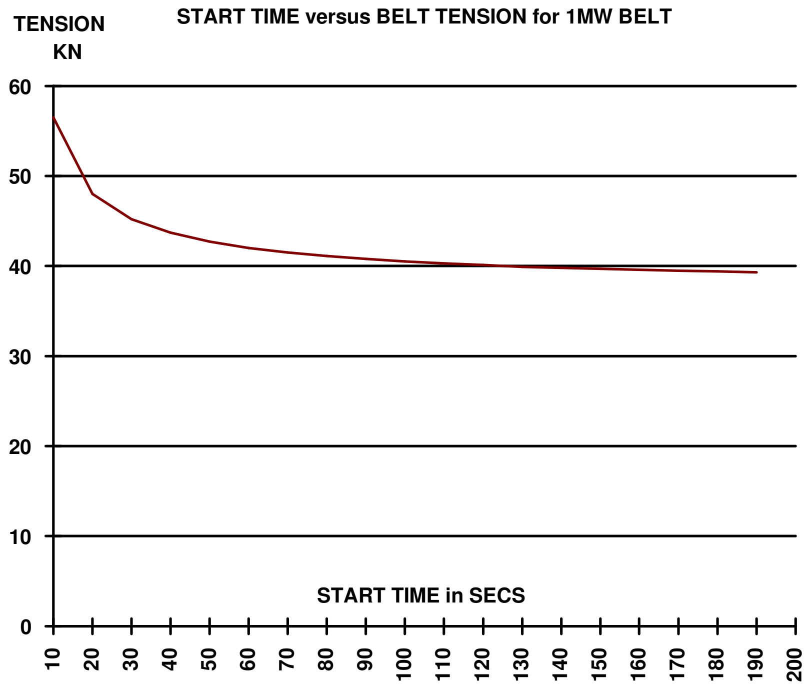
When looking at a piece of conveyor belting it is hard to imagine it stretching, but when used over several kilometres the conveyor behaves similar to an elastic band. As the drive head starts to turn, tension is applied to the belt in the forward direction. The maximum tension is applied at the drive head on the pulling side and is gradually dissipated along the carry strand, around the boot and along the return strand back to the pushing side of the drive head where there is minimum tension. Belting manufacturers will only warranty their belt if this calculated maximum tension at the drive head (Tmax) is less than one tenth the tested breaking strain of the belt. One would ask with this ten to one safety factor how can a belt break? The problem lies in the dynamic operation of the belt and not in it's simple static calculation model.



As a belt is started or as load is put on and delivered off the belt, tensions at various points of the belt change. As these tensions are applied, they are taken up as elastic stretch within the belt. If this stretch is not applied or released slowly and evenly, sudden changes in tension are likely to become dynamic tension waves that travel up and down the belt. These waves may take the form of transverse waves (similar to ocean waves) or compressional waves (similar to sound waves). Waves of tension add to or subtract from the overall average static tension calculated in the belt. If the peak of a tension wave meets a high tension point in the belt or another tension wave, then they may easily combine to break a belt. This usually occurs at weak points in the belt; ie. clips and splices. These tensions can be measured with sophisticated equipment, but are easily viewed as slapping in the loop take-up or variations in speed at the boot pulley.

STARTING THE CONVEYOR WITHOUT BREAKING IT

One of the most common causes of breaking belting is starting it too quickly. There are two compounding problems associated with starting a conveyor. The first is a simple static calculation that says the faster you accelerate a load, the more energy you need to do it and the greater the maximum tension at the drive head will be. Below is a graph showing the relationship between starting times and maximum belt tension. Note that this is a static calculation and makes no allowance for dynamic waves.



Note also, in the above graph, that the curve for low values of start time is logarithmic. This means that as start times approach zero seconds, starting tensions are approaching infinity.

The second problem is that the faster the drive head is accelerated the larger the tension waves generated. It is difficult for conveyor designers to accurately predict the type and size of tension waves in a conveyor because there are so many factors envolved. They are best observed by speed oscillations at the boot roller during starting or movement in the tension control system. Weight towers and loops should operate smoothly without oscillation. With a fast starting drive head, the conveyor may be at full speed before the boot of the conveyor has started to move. The conveyor is stretching to accommodate the accelerating drive head. As the elastic tension builds at the boot, it begins to move and tensions in the belt begin to equalise back to the static model. Here there is a sudden release of elastic energy that will cause a transverse *whip like* tension wave that travels the length of the belt.

During an ideal conveyor start the boot roller should accelerate smoothly and evenly without oscillation.

DRIVE DESCRIPTION

The clutch is placed between the driving force (an electric motor) and the driving pulley in various configurations.

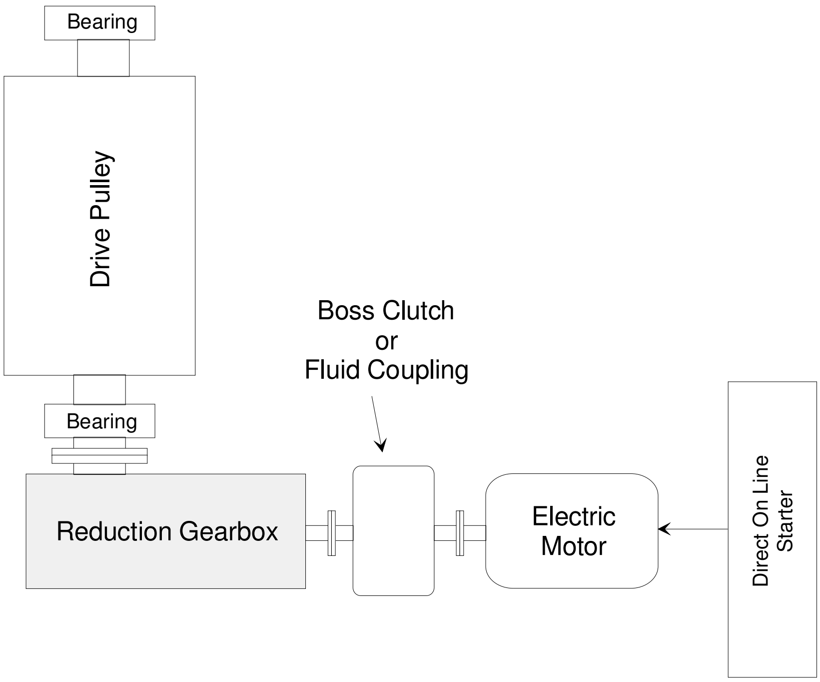


Figure 1
Plan layout of BOSS or Fluid Coupling transmission system

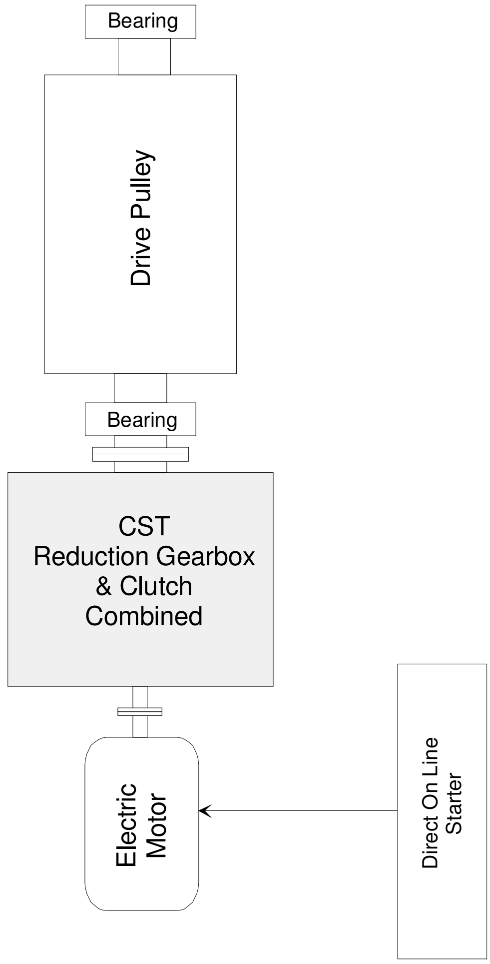


Figure 2 -Plan layout of Dodge's CST transmission system

OPERATING PRINCIPAL - CLUTCHES

The clutch controls the amount of torque (turning force) that the motor applies to the drive pulley. The transfer of energy through the clutch plates is controlled by a hydraulic piston forcing the plates closer together. The more pressure applied to the piston, the more energy the clutch transfers. A safety spring releases the clutch should the controlling pressure fail.

The clutch plates are immersed in oil which provides both cooling and a vicious medium between the plates for a smooth transfer of energy. The oil is circulated through the system by a pump and usually an external oil cooler is connected in series with the circulating oil.

Clutch starting systems have the advantage of :-

a) The electric motor is started on no load with a simple DOL starter,

b) No mains harmonics due to inverter control,

c) No deterioration of the motor winding insulation due to square wave switching,

d) No additional cooling required for the electric motor for long operation at low speeds,

e) Low temperatures maintained in the motor rotor,

f) High immunity to mains transients,

h) High efficiency when at full speed,

i) The control system is simple and easy to maintain,

j) High reliability.

OPERATING PRINCIPAL - FLUID COUPLINGS

Fluid (or Hydrodynamic) Couplings consist of two bladed wheels. One is attached to the drive and the other is attached to the load. These two halves are called the centrifugal pump and the turbine. These blades are surrounded by a shell and form a working space in which the operating fluid circulates. Mechanical power is transmitted as the fluid flows continuously between the pump and the turbine. In order to transmit power there must be a difference in speed between the pump and the turbine. The difference is usually quoted as a percentage of "full input speed" slip.

Varying the amount of oil in the chamber between the two bladed wheels will vary the amount of power or torque that can be transmitted to the load. Once the conveyor "break away" torque has been reached by the coupling, only a small increase in torque is required to accelerate the conveyor to full speed. (10 to 20%)

It is a common misconception that adjusting the scoop position, works like changing gears on a car to provide speed control.

Fluid couplings are not 100% efficient and power is lost in the form of heat. Heat increases in proportion to the slip. If excessive heat is generated, then the oil may break down and power will be lost. Variable scoop couplings have an oil circulating pump and a cooling fan to ensure the oil temperature is maintained within limits. If the conveyor is stopped and the coupling oil still requires cooling, then a bypass solenoid is operated so that oil may pass through the pump and cooling system. The cooling system is controlled via a temperature sensor and runs independently of the conveyor running.

Two reversing relays control the direction of the screw drive attached to the scoop. This scoop drive comes complete with a scoop drive brake that must be lifted as the "in" and "out" relays are energised. The scoop is driven out to increase transmitted torque and driven in to decrease transmitted torque from the coupling. Limits detect when the scoops are fully in and fully out.

The scoop couplings have the ability to adjust the torque to the conveyor. This is done by varying the amount of oil transferring energy inside the coupling.

One peculiarity with variable scoop fluid couplings is the change in oil level requirements to transfer torque dependant on the relative speed of the pump and the turbine. In plain English, when there is a high speed difference between the pump and turbine, (low output speed) a very small change in oil level makes for a large change in transmitted torque. When there is a low relative speed between the pump and the turbine (high output speed), the oil level change has to be much greater to implent and equal change in torque. In pulsing systems, this means that short withdraw periods are required at low speed and larger withdraw periods are required at high speed to provide a linear ramp.

OPERATING PHILOSOPHY

From a situation where the conveyor is at stand still, the torque applied to the conveyor is gradually increased until there is sufficient force to overcome the stationary friction and mass of the conveyor and it begins to move. This point is called the "breakaway point". The amount of torque required to reach this point varies, dependant on the load of the conveyor and the conveyor's overall mass. It can be said that accurately determining the breakaway point is the most critical part of providing smooth and even starts. Although slowly increasing torque until breakaway is achieved, may seem like wasting time, it is a very important function. Once breakaway has occurred, the rate of acceleration of the conveyor to full speed is now dependant on the torque applied above the breakaway value. **f = ma** With a constant force on a constant mass, a constant acceleration will be achieved. However with a conveyor, as idlers and pulleys turn faster, there is a small percentage increase in required force to continue the acceleration toward full speed. This is because of increasing centrifugal forces. i.e. It requires more energy to turn a rotating device faster. Once full speed is reached, the acceleration torque will then drop back to the required running torque. The ratio of accelerating torque compared to running torque is logarithmically related to the starting period. The longer the start, the less starting torque required to achieve it.

In these examples: s = seconds and RT = run torque.

Approximately – 10s = 1.8 RT, 14s = 1.6 RT, 20s = 1.4 RT, 40s = 1.2 RT, 90s = 1.1 RT.

A typical control system uses a tight PID loop which controls the amount of power that the drive motor applies to the conveyor belt. A second PID loop adjusts the set point for the motor power to compensate for variations in load and produces a pre-determined acceleration regardless of load. Using this method, conveyor belts may be accelerated anywhere between thirty and three hundred seconds. It has the advantage of starting the motor on no load and using only slightly more motor torque than is required to run the belt fully loaded during the starting period. This prevents over heating of the motor rotor and greatly reduces wear and tear on the belts, drive pulleys and gear boxes. Belt tension oscillations are reduced, preventing breakages of clips and splices and excessive tension & speed requirements from loop takeups. Smooth starting also prevents belt flapping over concave curves in the conveyor profile. It will also help in the prevention in spillage.

STARTING TECHNIQUES

There are several techniques for starting a conveyor. Each technique has advantages and disadvantages over the other. Listed below are the methods commonly used and a brief discussion of advantages and disadvantages. A linear speed start will provide the least stress and damage to a conveyor system.

SPEED CONTROL

Speed control is implemented with the following PID algorithms (SEE FIG 3). The desired starting curve is fed into the speed set point. This is then compared to the actual speed of the conveyor. The error between the two is used to set the amount of torque delivered by the motor via a PID formula. At any time if the actual conveyor speed is faster than the speed set point, the torque set point will be lowered. Vica versa, if the actual conveyor speed is slower than the speed set point the torque set point will be increased.

The torque set point is then compared to motor torque feedback signal and the error between them is used to control the pressure applied to the clutch plates via a PID formula.

For variable scoop or variable drain couplings, the output control PID is replaced by a variable pulse of the scoop/drain drive. As there is a delay between movement of the scoop / drain control arm and the oil between the pump and the turbine of the coupling, each motion should only be of short duration with a reasonable period between to allow the coupling to settle before the next sample. Typical values are a pulse for 1 second and then a delay for 2.5 seconds before the next sample.

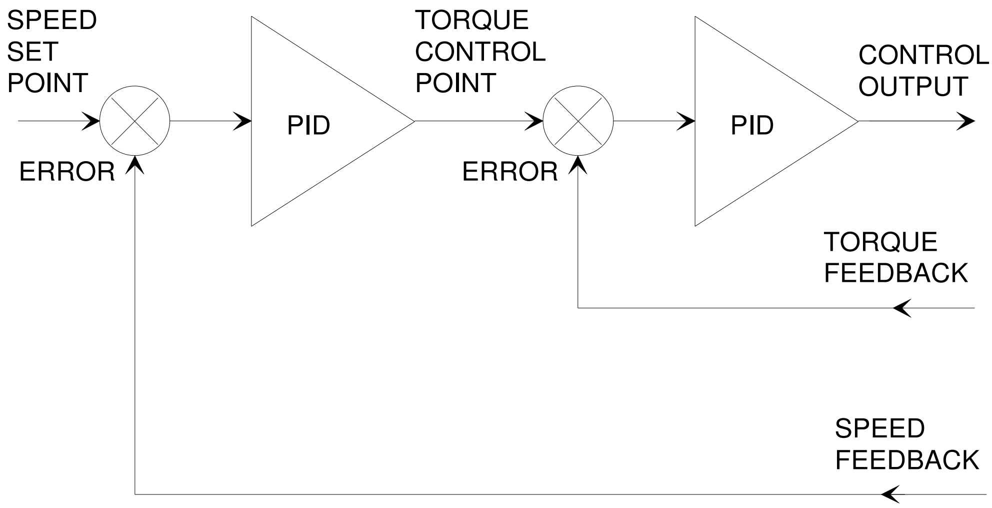


Figure 3

Typical speed control system

The speed set point provides the shape of starting curve that you would like the conveyor to follow. Below is an example of speed starting curves.

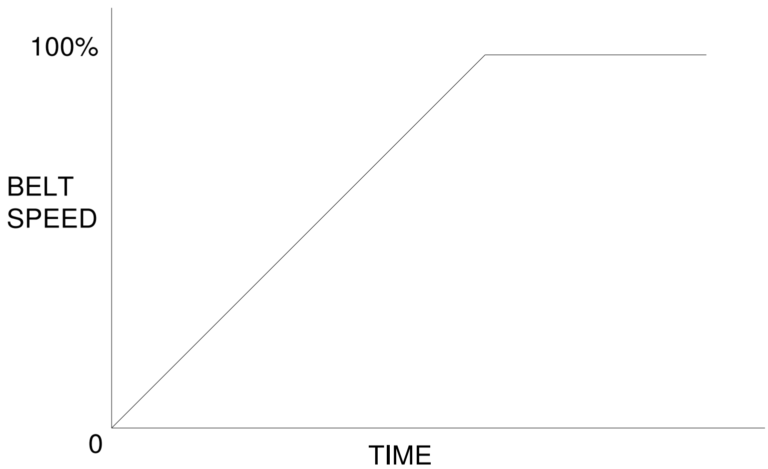


Figure 4

LINEAR RAMP

A linear ramp has the advantage that it requires the minimum possible torque to start a conveyor. It is also the simplest to implement with the output of a counter providing the curve. By varying the count rate, the slope of the line and therefore the starting period is easily adjusted. It is best suited to conveyors under 1.5 kM without trippers.

It's disadvantage is that there is a sudden change in torque requirements the instant the conveyor reaches full speed. This knee in the torque requirements causes tension waves in the conveyor that usually dampen out within 15 seconds. The sharper the knee, the larger the tension waves. The longer the starting ramp, the smaller the change in torque when full speed is reached and therefore the smaller the tension waves. The tension waves can be seen as oscillations in motor current and movement in the tension take-up.

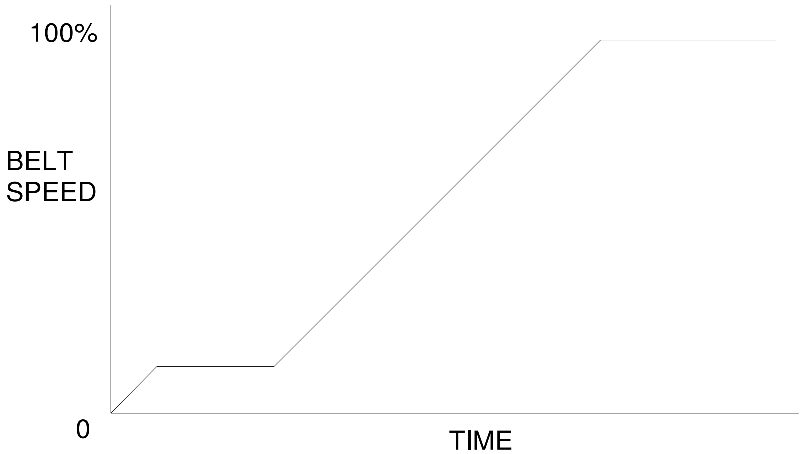


Figure 5

LINEAR RAMP WITH PRE-STRETCH

This ramp still has the advantage of minimum starting torque requirements, but provides a period of slow speed (usually 10%), to fully stretch the conveyor before accelerating it. This helps the situation in long stretchy conveyors where the drive head may be at considerable speed before the boot begins to move. This places the conveyor in speed catch up mode which causes tension oscillations and speed variations that make control difficult. It is best suited to conveyors over 1.5kM or those with very stretchy belting. (2 to 3% stretch for rated load). It is still simple to implement by holding a counter for the period of the pre-stretch.

It's disadvantage is still the tension oscillations that occur once the conveyor reaches full speed.

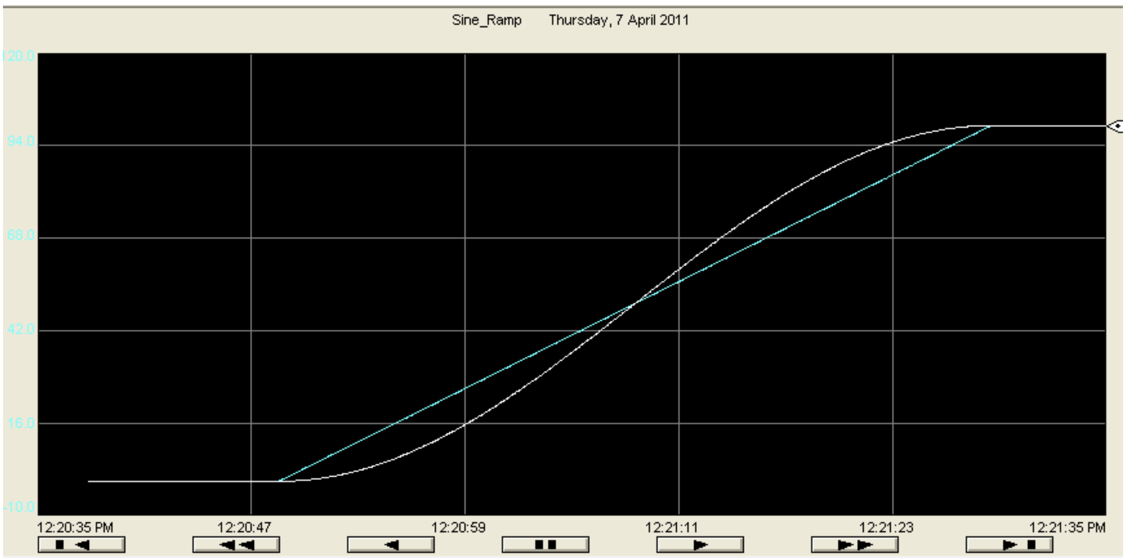
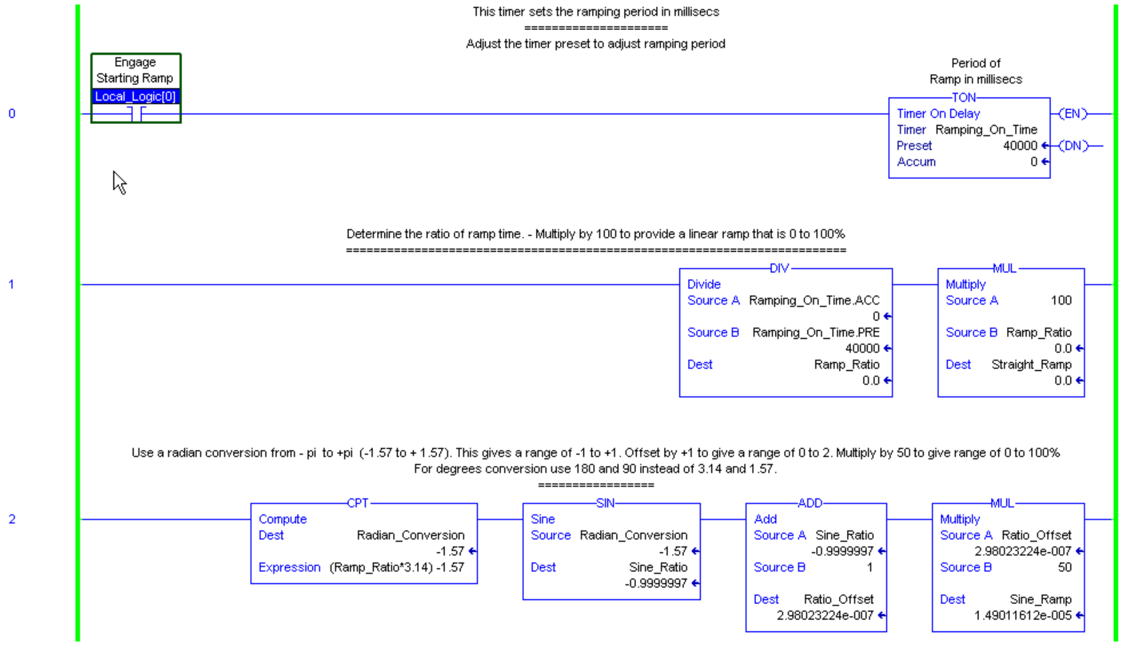


Figure 6

SINUSOIDAL STARTING RAMP

The sinusoidal starting ramp has the advantage that it produces the smoothest possible changes in acceleration and therefore no sudden changes of tension are generated. This stops tension waves in the conveyor and makes holding control easier. The slow acceleration at the bottom of the ramp is ideal to allow for conveyor stretch before acceleration.

It's disadvantage is that it's control is more difficult to design and implement. It is typically achieved via a look-up table or requires a PLC with advanced maths capability. Another disadvantage is, for a given starting period, it will have a higher torque requirement at the 50% speed point and therefore generate a higher tension in the conveyor than a linear ramp.



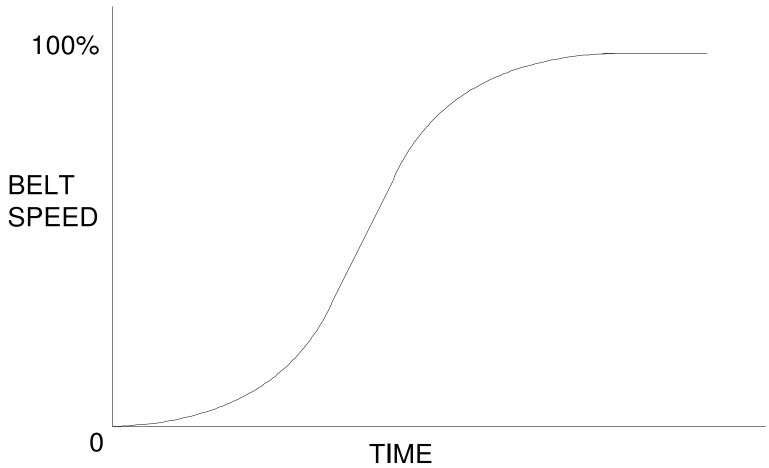


Figure 7

S CURVE STARTING RAMP

An S curve starting ramp is a compromise between the linear and sinusoidal starting ramps trying to use the advantages from both. The slower lead in is used as a pre-stretch, the linear middle section reduces the maximum torque requirements and the roll off at the top reduces tension waves that are caused by sudden changes in acceleration.

It's disadvantage is that it is more difficult to implement in control and requires a look-up table.

ACCELERATION CONTROL

It is the nature of PID control systems that there must be an error between the set point and the feedback signal before the output control signal will change. The greater the error the more the output signal will change to try and bring the set point and feed back signal back to the same value. Increasing either the proportional, integral gains will make the control system respond quicker to errors, but due to natural lags in the mechanical system, may over respond and cause oscillation in the system.

With conveyor control it is better to err on the side of slowness in the control system than to cause even the slightest oscillation in the conveyor. Oscillations cause variations in speed which generate tension waves.

When using speed control, the actual speed may be forced into error by unpredictable influences in the conveyor system. These include :-

a) Change in torque requirements due to an unevenly loaded conveyor moving along a changing profile. This may cause a speed up or slow down of the conveyor.

b) A tension wave caused by a heavily loaded boot stretching and then contracting the conveyor as it is accelerated.

c) Operation of the tension control winch in an imperfect way.

d) Tripper drives causing speed oscillations as they control based on tension.

e) Conveyor belting rubbing on structure or material jamming in rollers and pulleys.

In each case the control system will try to return the actual speed back to the speed curve. This will require extra torque if the conveyor has dropped behind or less torque if the conveyor has over-sped. There will invariably be some over shoot and therefore a speed oscillation in the adjustment which will cause a tension change in the belting.

Acceleration control, as opposed to straight speed control, addresses this problem by controlling the rate of acceleration instead of actual speed.

.

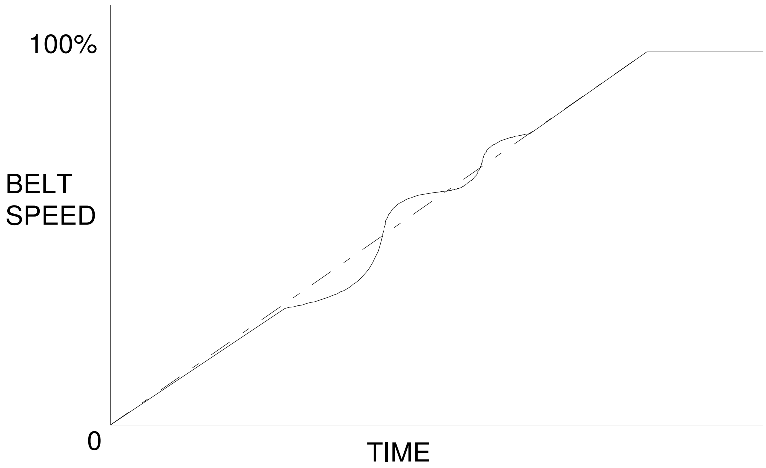


Figure 8

Typical re-action to sudden load change using speed control

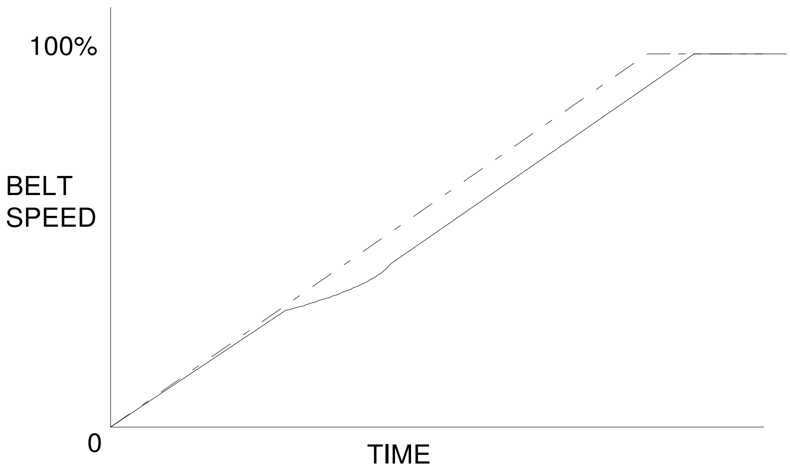


Figure 9

Typical re-action to sudden load change using acceleration control

It can be seen by comparing figures 8 and 9, acceleration control will produce smoother results for sudden changes in load when starting a conveyor. There is a slight penalty in overall start period, but this is far outweighed by the advantages of reducing tension waves. For the purposes of clarity a linear speed ramp was selected, but reactions would be similar for other speed based starting curves. Acceleration control is implemented similarly to speed control with a double PID loop but with some extra calculations required. The acceleration control set point shape is also different.

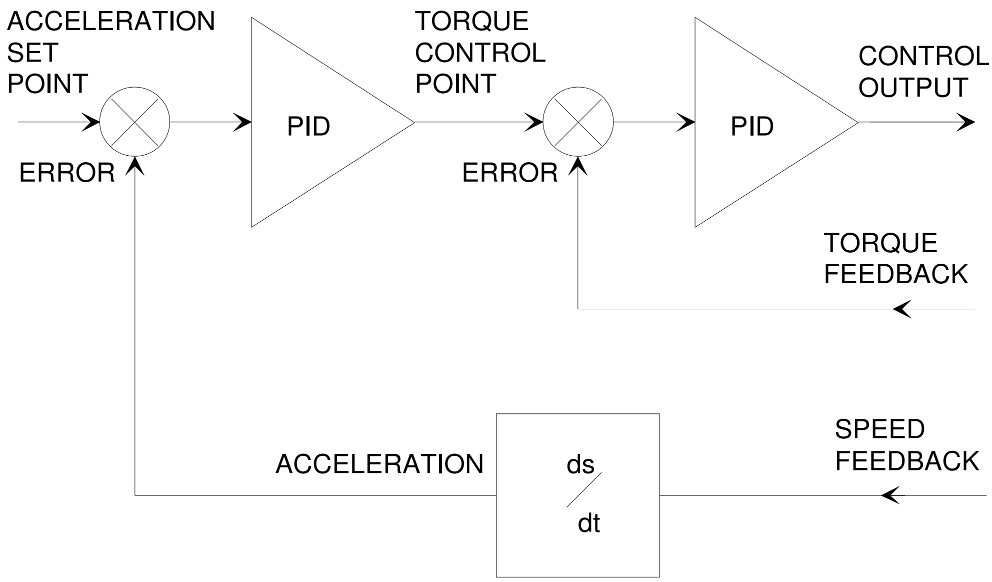


Figure 10

Acceleration control configuration

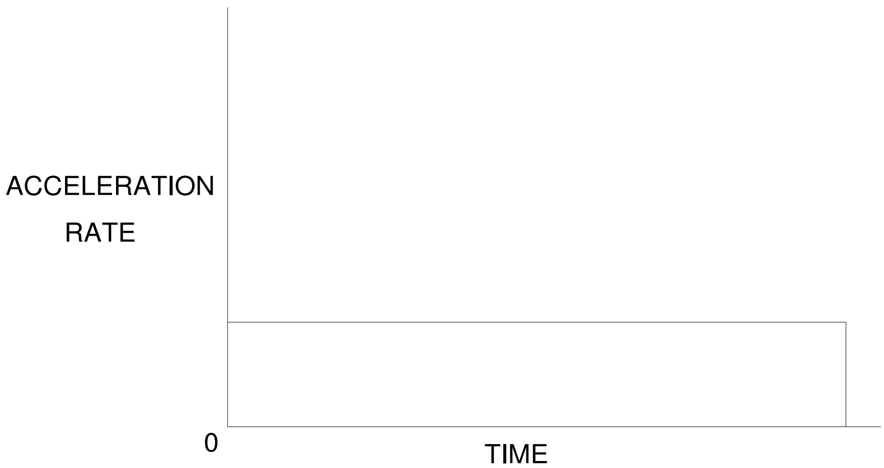


Figure 11

Linear ramp using acceleration control

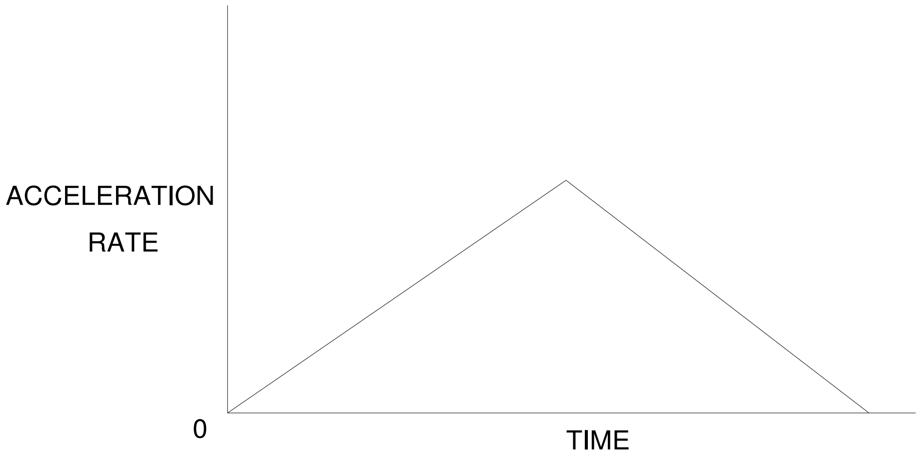


Figure 12
Modified sinusoidal ramp using acceleration control.

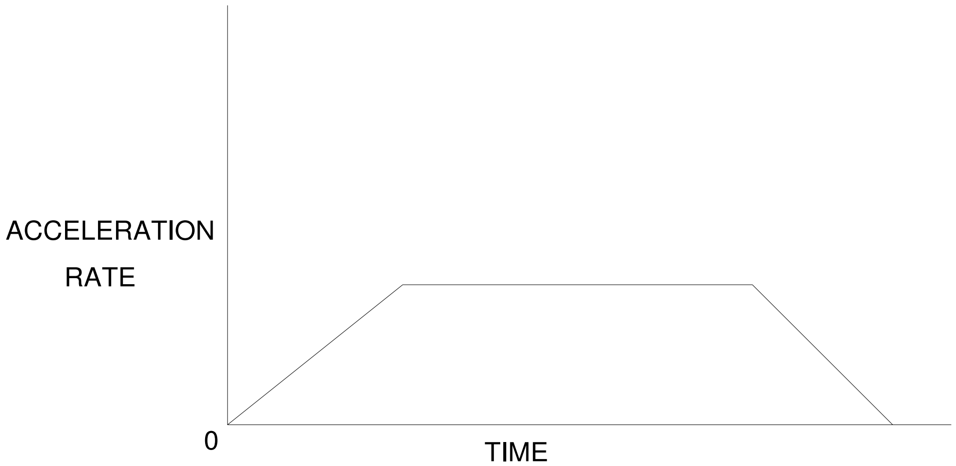
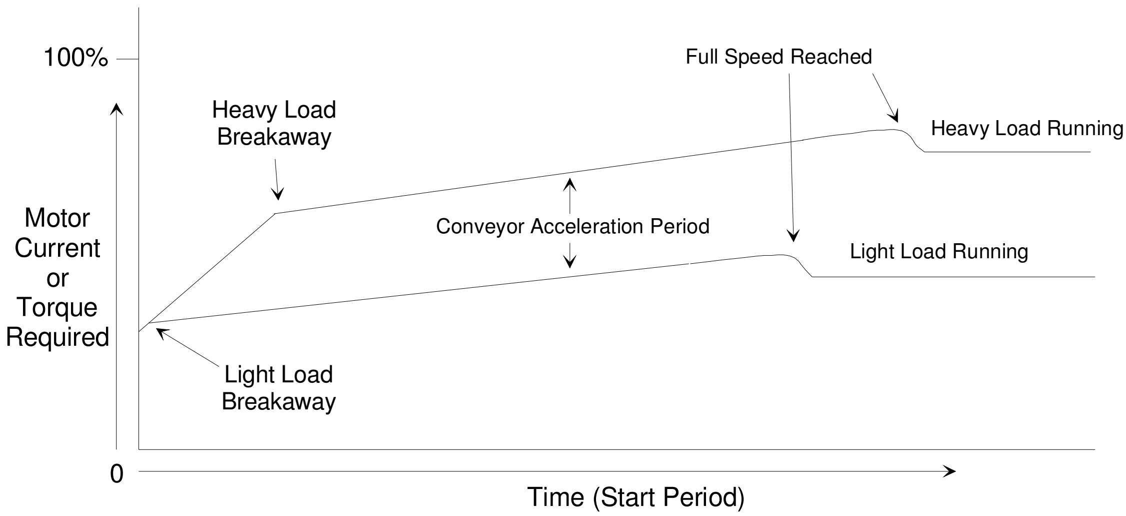


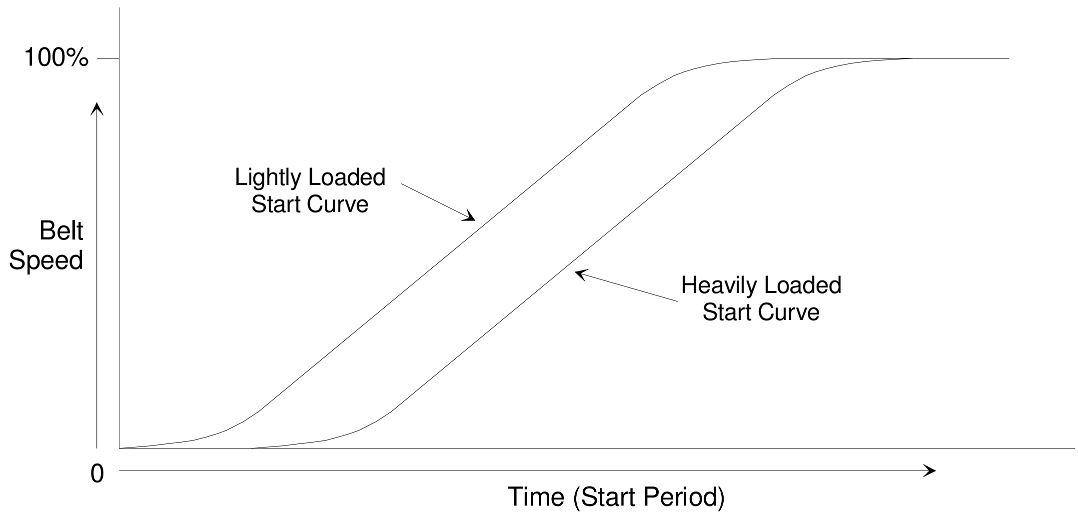
Figure 13
Acceleration set point control to give an approximate S shaped start.

As can be seen from figures 10 through to 13 acceleration control requires more work in the PID network but control set points are easier to generate than those used for speed control.

CURRENT RAMP CONTROL

Sometimes there is a situation where only a crude form of speed feedback exists, such as a proximity detector that only detects one or two pulses per revolution of a pulley. This is not sufficiently accurate for low speed control. However it can detect the break away point and give a reasonable indication of the conveyor at full speed. In these circumstances a current ramp can be used instead of a speed control closed loop system to provide a reasonably linear start. These will not be as accurate as speed feedback starts, but still provide a smooth enough start to dramatically reduce tension waves compared to other methods. The following diagram illustrates the motor current profile to provide linear starts for a conveyor.





Starting from a stationary position a conveyor start would take the following steps:-

Perform prestart functions such as Prestart alarms, and brake release.

Start electric motors.

Slowly increase torque from variable torque device until breakaway point is detected.

Read motor current value and store as breakaway current.

Calculate (1.2 x breakaway current) and develop a motor current set point ramp that increments from breakaway current through to (1.2 x breakaway current) over the desired starting period.

Vary the torque of the variable torque transmission so that the motor current tracks the ramp until full speed is reached.

Drive variable torque device to full required torque. The conveyor is now running.

LOAD SHARING

Load sharing is generally not a major issue in fluid drives where there is a soft relationship between slip speed and torque transmitted. However when motors are driven on two different pulleys, or it is necessary to take all drives close to their maximum power, it is prudent to implement some form of load sharing.

When using multiple drives at a drive head or tripper, there is a tendency for one of the drives to take more of the load than others. This is due to several factors :-

1) Speed variation between the drive drums due to slightly different drum diameters.

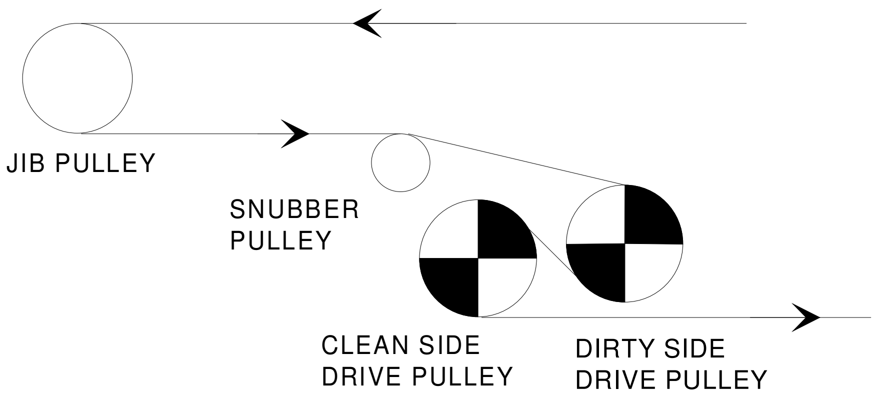


Figure 14

Figure 14 shows a typical dual drive configuration. For a dual drive situation one motor is placed on each drive pulley. Even if both drive drums are machined exactly the same, uneven wear on drum lagging and a build up of material on the drums will cause slight variations in drum diameter. A small variation in diameter means that the surface speed will change by 3 times that diameter. eg. The dirty side drive has a build up of material on the drive pulley of 0.5%. This will cause the dirty side drive motor to slow down by 1.57%, placing extra load on the dirty side drive. The tighter the full load % slip specification of the motor, the greater % of the load will be taken by that motor. If a motor of F.L. 1.0% slip was used it would probably trip on overload.

2) Belt construction

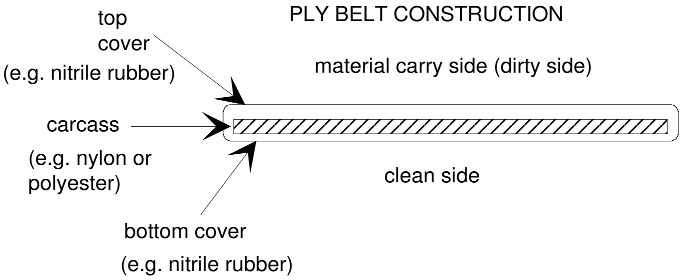


Figure 15

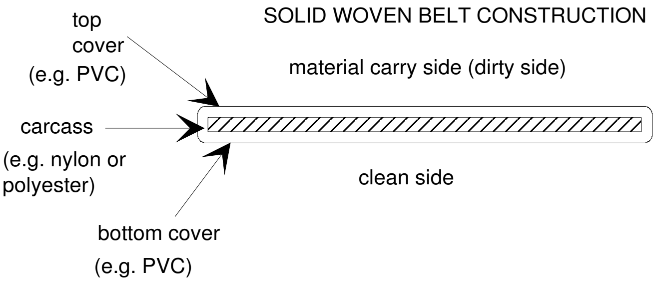


Figure 16

Figures 15 and 16 show a cross sectional view of two commonly used belts in underground mining. The carcass provides the strength of the belt and is typically made from either nylon or polyester or a combination of both. Nylon is cheaper but has up to 3% stretch when loaded. Polyester has typically 0.8% stretch when loaded. When driving the belt it is the carcass that carries the load and tension, therefore when calculating torque around a pulley, it is necessary to calculate to the centre of the carcass. As can be seen from figure 15 the centre of the driving force may not be in the centre of the belt. This means that in clean side - dirty side drive situations there is a smaller diameter of applied torque on the clean side drive to the dirty side drive. This imbalance contributes to unequal load sharing by the drives.

3) Wear

Under normal use the top cover of a belt will chip with the impact of material and the bottom cover will scrub away as it is the face in contact with the rollers. This wear is often at an uneven rate and can effect the drive diameter of the drives at the drive head. Lagging on the drive drums will also wear away and usually at a different rate for each of the driving pulleys. These wear factors all influence the load sharing of the driving pulleys no matter how well matched they were when installed.

4) Power Imbalance

When three drives are installed, two motors are connected to one drive pulley and a single motor is connected to the other. If the two pulleys are of matched diameter and the pull of the belting is symmetrical, then the two motors on the one pulley will have to do half the work of the third.

Load sharing between multiple drives can be achieved in one of three methods using wet clutches. In these next descriptions the term '**lock-up**' will be used. This in fact does not mean that the clutch is actually locked, as in the case of placing a pin through the plates but means applying a pressure to the plates that transfers sufficient torque under normal running conditions not to slip. This pressure should not be so great as to disallow the clutch to slip when and abnormal condition, such as a jammed boot, occurs. The clutch can then act as a safety release, preventing further damage to the conveyor.

In the past clutch pressure has been set too high in multiple drive situations. The uneven load share has either caused slip on the belt or slip in the clutch. Slip on the belt has caused excessive wear on the slipping pulley. Slip in the clutch, at a much higher torque than desired, will hammer indentations into the clutch drive spline.

LOAD SHARE METHOD 1

Locked up drives with pressure relief. In this situation both clutches use controlled pressure during the ramping stage until full belt speed in reached. Once at full belt speed the drive drawing least current is driven to lockup with sufficient pressure to transmit approximately 130% of full load motor current. The drive drawing the most current during normal running is locked up with sufficient pressure to transmit 110% of full load motor current. Once the high current drive draws 110% full load current it's clutch will slip transferring some extra load back to the other drive for a short period. As the heavier loaded drive is running slightly faster than the lightly loaded one it will gradually increase it's share of the load over a period of time until it slips again. The rate of load share increase is dependant upon the mis-match in the speed of the drives.

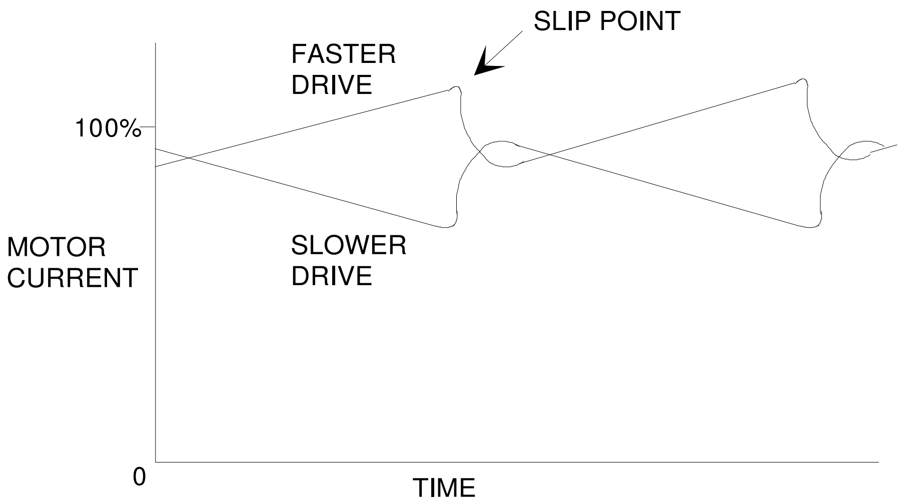


Figure 17

The slip point of the faster drive may of course be set lower than 110% if required, however care should be taken to ensure there is sufficient pressure to start the conveyor.

The advantages of the method illustrated in figure 17 are :-

1) It is simple to implement.

2) Requires no change to PID tuning as conveyor conditions change.

3) Only slips the clutch for small periods of time, keeping heating and clutch wear to a minimum.

4) The drive pulleys are machined and lagged the same and therefore inter-changeable.

It's disadvantage is slight unevenness in current between motors. Although this is not harmful to the motors on an installation that is required to use all of the installed power, motor overloads may occur at peak load periods.

LOAD SHARE METHOD 2

Locked up drives with pressure relief and controlled pressure on the high current drive. In this situation both clutches use controlled pressure during the ramping stage until full belt speed in reached. Once at full belt speed the drive drawing least current is driven to lockup with sufficient pressure to transmit approximately 130% of full load motor current. The drive drawing the most current then has its torque or applied pressure value gradually decreased until it is drawing the same current as the lockup up drive. A slow algorithm then adjusts the output to the non-locked device to follow the locked devices current. The algorithm is a simple compare and then either increment or decrement the output to the slipping drive based on the error. The routine would be run on a regular cycle of 0.5 secs or so.

The advantages of the method are :-

1) It is simple to implement.

2) Requires no change to PID tuning as conveyor conditions change.

3) Only slips tone clutch slightly, keeping heating and clutch wear to a minimum.

4) The drive pulleys are machined and lagged the same and therefore inter-changeable.

It's disadvantages are:-

1) Care must be taken in developing of the algorithm. Clamps must be applied to outputs to ensure roll-over cannot occur.

2) During the life of a conveyor, pulley wear can swap which drive will draw the most current.

3) If the current draw is close, the drive drawing the most current can be dependant on conveyor load.

LOAD SHARE METHOD 3

Single drive locked others slipping. This method requires the use of different diameter pulleys or different gearbox ratios to give a speed differential between one drive and the others.

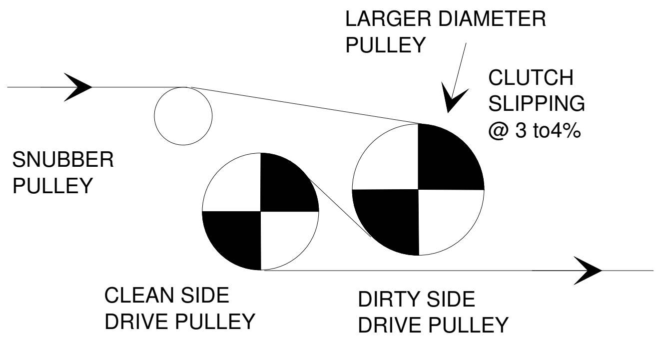


Figure 18

Figure 18 shows how a larger diameter pulley is used on one of the drive drums to provide a permanent slip at 3 to 4% of full speed on the clutch fitted to that pulley. The smaller diameter pulley is 'locked up' and controls the speed of the conveyor. The larger pulley's control is a slave of the locked up pulley's motor current. This arrangement is shown in figure 19 below.

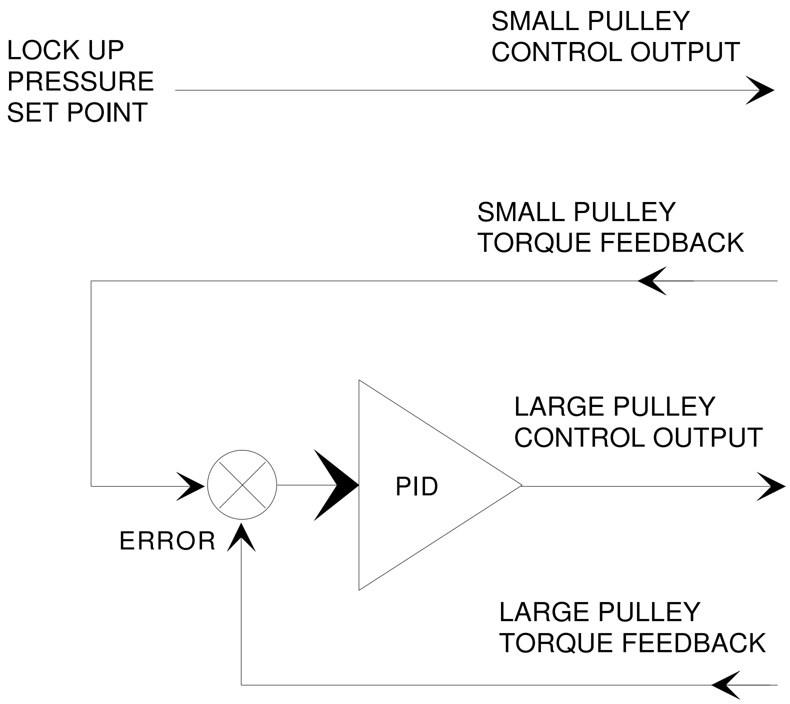


figure 19

In figure 19 the torque requested by the large pulley is a direct slave of the torque feedback signal from the small pulley. The PID controlling this slaving operation should be gentle in action to prevent current hunting between the two drive rollers.

The actual pulley to lock and the one to slip will vary from drive-head to drive-head depending on the pulley configuration, however the control functionality will remain the same. Pulley diameter size changes may also be achieved with the thickness of lagging alone.

The advantages of this configuration are :-

1) Equal sharing of motor currents under all conditions so that maximum installed power may be utilised.

2) Tuning requires little attention as conveyor conditions change.

The disadvantages of this configuration are :-

1) One clutch is permanently slipping, generating more heat and wear than the locked up unit.

2) Different pulley sizes mean they are not interchangeable and care must be taken when relocating the drive-head.

LOAD SHARE METHOD 4

All drives slipping.

In this method no drives are 'locked up' with the system being controlled at a few percent under full speed. All pulley diameters are the same size with variations due to wear and belt torque radius being adjusted for with slight variations in clutch slip speed.

There are two load share methods used with this technique with only slight differences in reaction time between them.

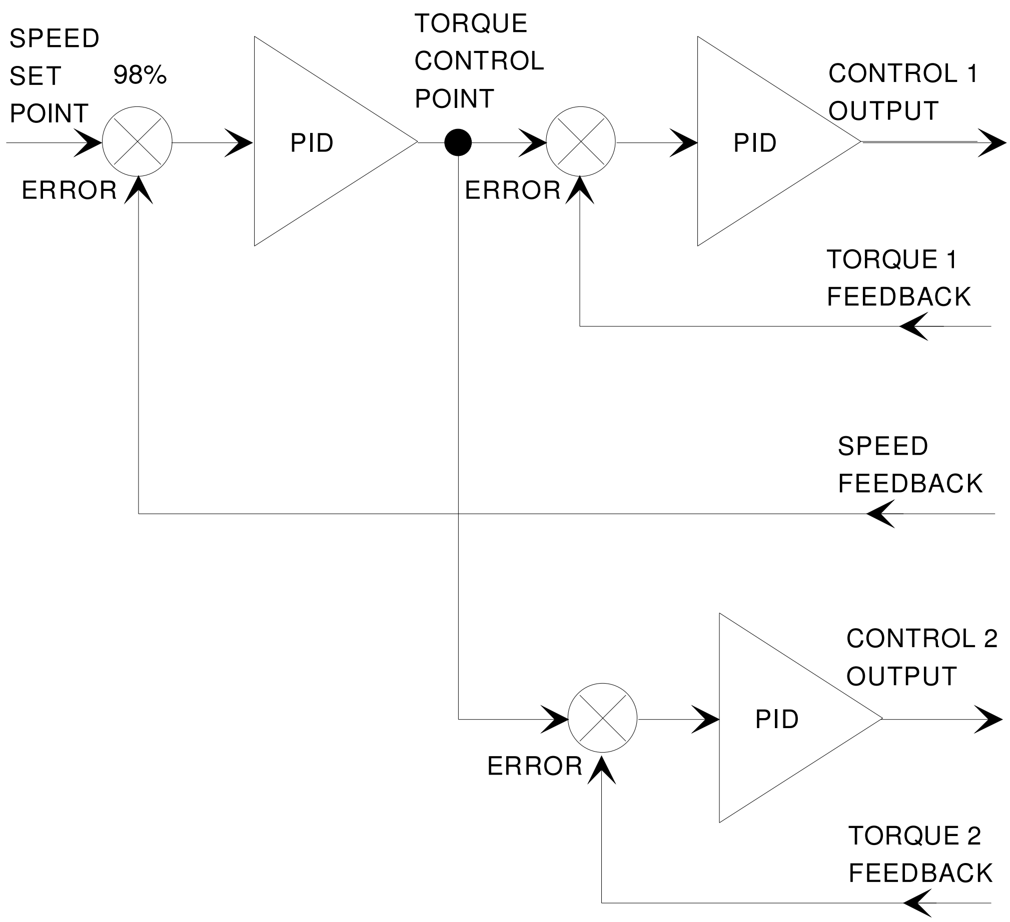


figure 20

In figure 20 the speed PID provides a torque set point for all drives. As load changes occur both motors are given the same signal to change torque. This allows any drive to removed or added without the need for master slave operation. If any drive is removed, then there need be no changes to the control system apart from increasing the speed PID gain and turning off the appropriate motor.

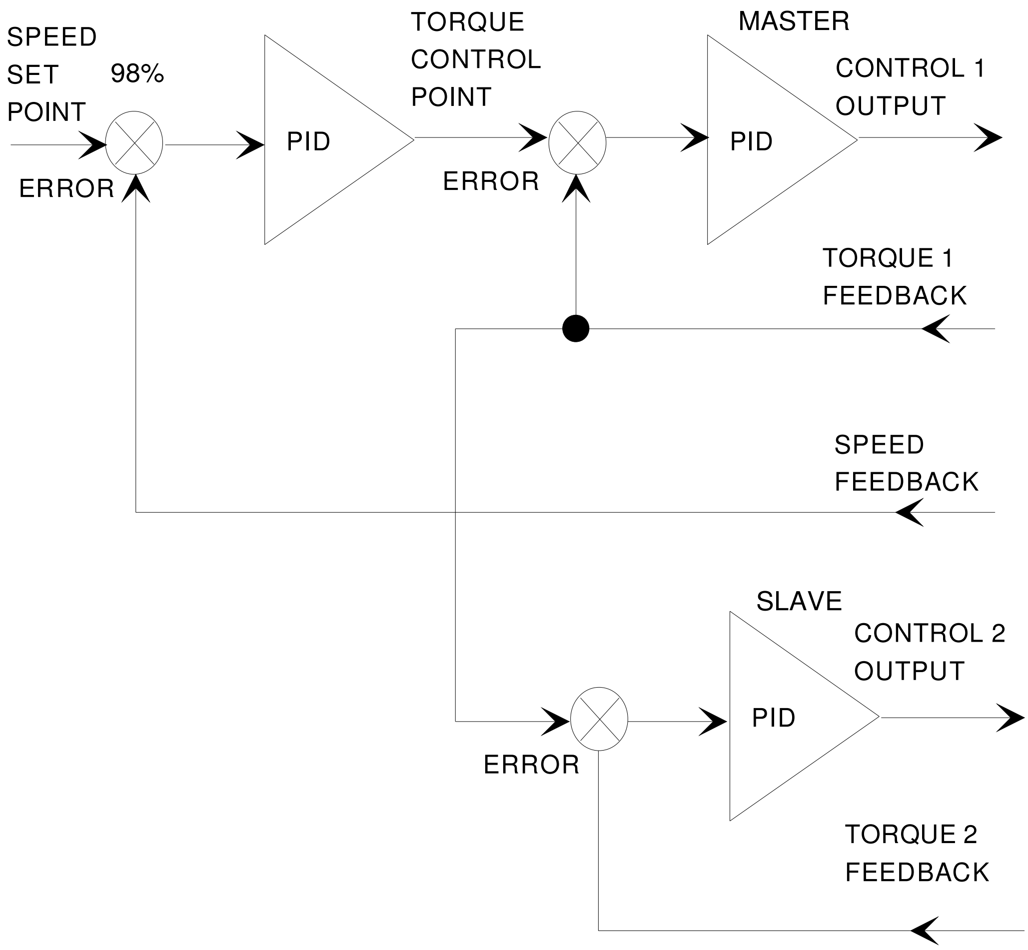


figure 21

In figure 21 the speed PID supplies the torque set point for the master drive and all other drives are slaved off the feedback from the master drive. This means that the master drive must change value before other drives will change and the master drive must be left when excess drives are removed or the control code re-written for a new master.

The advantages of this configuration are :-

1) All pulleys and gear boxes are the same diameter and ratio.

2) Even motor current sharing allowing the use of maximum installed power.

The disadvantages of this configuration are :-

1) All clutches in permanent slip with maximum losses due to heating. It should be noted here that although a theoretical 1% slip is achievable, it more practical to hold 2% slip and experience has shown that as belt and pulleys wear unevenly, and material builds on pulleys, 3 or even 4% slip speed set points may be required to maintain load sharing.

2) It is the most complex of the control systems used and will require tuning changes as the conveyor conditions change.
3) Where this system has been implemented in clutch systems, lockup and the consequent loss of load sharing has occurred on a regular enough basis for configuration to be change out for method 2.

LOAD SHARE METHOD 5 –

SINGLE DRIVE ADJUSTMENT DURING START

This technique can be usd where integer math control is implemented and provides a very accurate method of load share. At the end of the calculation of error between the desired acceleration or speed control set point and the actual feedback value, an error value is created that would normally be used to adjust the output of all control values. Instead of adjusting all control values, if an increase is required, the lowest of the drives is increased. If a decrease is required the highest of the drives is decreased. This method provides very accurate load sharing despite verying external influences such as pulley diameters and varying oil conditions.

TRIPPER CONTROL

Tripper drives are drive stages that are installed in the middle of the carry strand of conveyors. They assist in lowering the maximum tensions behind the drive-head by spreading the power along a conveyor. Further distances may achieved with a single conveyor or cheaper, lower strength belting may be used as maximum tensions are lowered.

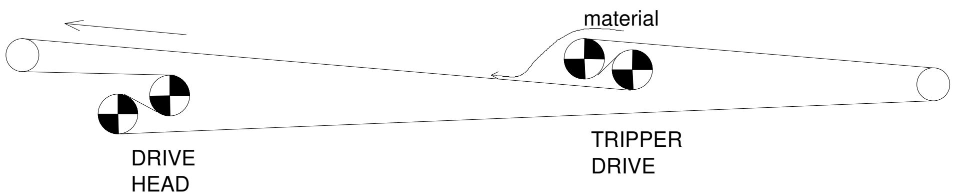


figure 22

Two types of control have been tried with tripper installations. These are power sharing and tension control.
Power sharing does not take into consideration unevenly loaded conveyors and has problems with standing waves between the drives.
Tension control allows each drive to take load according to the needs of the conveyor and guarantees that belt tensions do not exceed limits. In principle, a tripper drive monitors the tension in front of it and applies enough torque to keep this tension constant. The maximum tension seen

in-bye of the drive-head is the total of the energy (tension) required to move the belting and load between the tripper and drive-head and the tension in front of the tripper drive.
That is the maximum tension at the drive head is the tension in KN in-bye of the tripper, plus the tension in KN required to haul the empty belt between the tripper and the drive head, plus the tension inKN required to haul the coal between the tripper and drive head.
By adjusting the **tension set point** at the tripper on a fully loaded conveyor, appropriate load share is achieved between drive head and tripper and belt tensions are kept to a minimum.

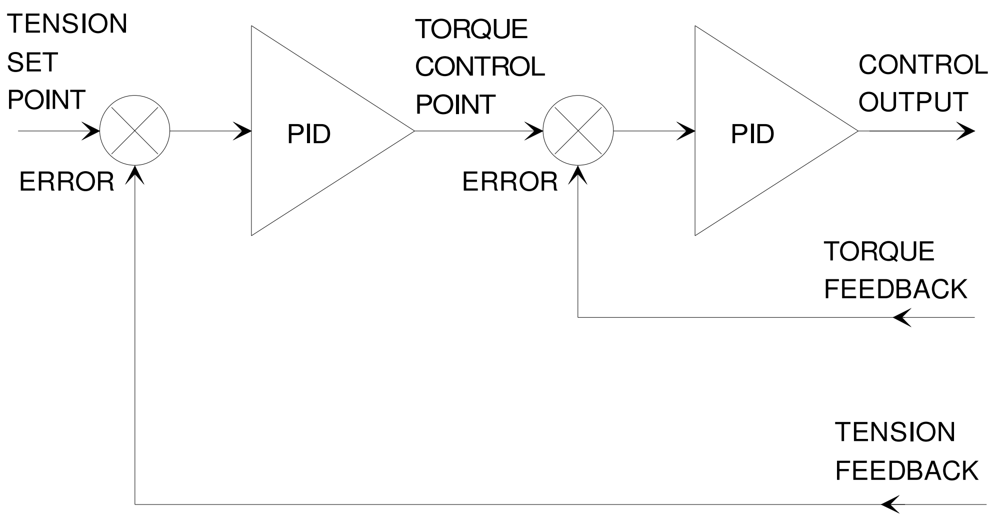


Figure 23

Figure 23 illustrates the control requirements for tension control using trippers.

TRANSDUCER SELECTION

As with any computer control system, the reliability is often lowered by external field devices. The information they provide or transmit and their susceptibility to damage makes them the weakest link in the chain. There are three components crucial to the starting control of conveyors with wet clutches or fluid drives and these are :-

1) The torque feedback signal.
2) The speed feedback signal
3) The hydraulic pressure control output.
4) Scoop or Drain control arm for fluid couplings.

In a closed loop system if any of these fail, catastrophic results may occur.

TORQUE FEEDBACK SIGNAL

The motor torque feedback signal can be measured by either a motor power transducer or a motor current transducer. True motor power is more accurate than motor current for determining torque (in phase current), but as this is part of the inner control loop, the outer control loop will adjust this value accordingly. Therefore high levels of accuracy are not required. In general motor current transducers (ie. CTs and 0-5a to 4-20ma transducers) are more reliable and cost less than power transducers and are therefore more commonly used. Measurement of a single phase to the motor is sufficient for both torque control and load sharing. Overload units are best equipped to protect for phase current imbalances. It should be noted that the torque PID loop is run at under 0.5 seconds and therefore current or power transducers that are interrogated serially may not be suitable. However a comparison of the two may be useful for transducer failure.

SPEED FEEDBACK SIGNAL

The speed feedback signal is a critical value and gives most problems with installations. It is worth spending extra engineering time and money to ensure that is reliable and accurate. It may be generated by tachometer, encoder or proximity detector. The transducer may monitor either the speed of the driving pulley or the speed of a freewheeling pulley. In either case the other point will need to be monitored by the conveyor control system to ensure that drive pulley slip does not damage the belting. In multiple drive systems each individual drive pulley will require slip monitoring. Operating range of the units must also be considered as it its important to have a smooth signal at low speeds. For frequency types, at least 50 Hz at full speed is necessary to give reasonable results at low speeds.

Tachometers - provide an output voltage or current proportional to speed. Voltage types are usually a wound armature rotating in a fixed magnet stator and cannot be adjusted except via voltage divider at the PLC. They require maintenance of brushes and commutator on a periodic basis. More recently Ringway has designed a 4 to 20ma adjustable electronic tachometer for this purpose. It is a sealed brass unit using infrared beam technology.

Tachometer Mounting - Below are some typical mounting examples :-

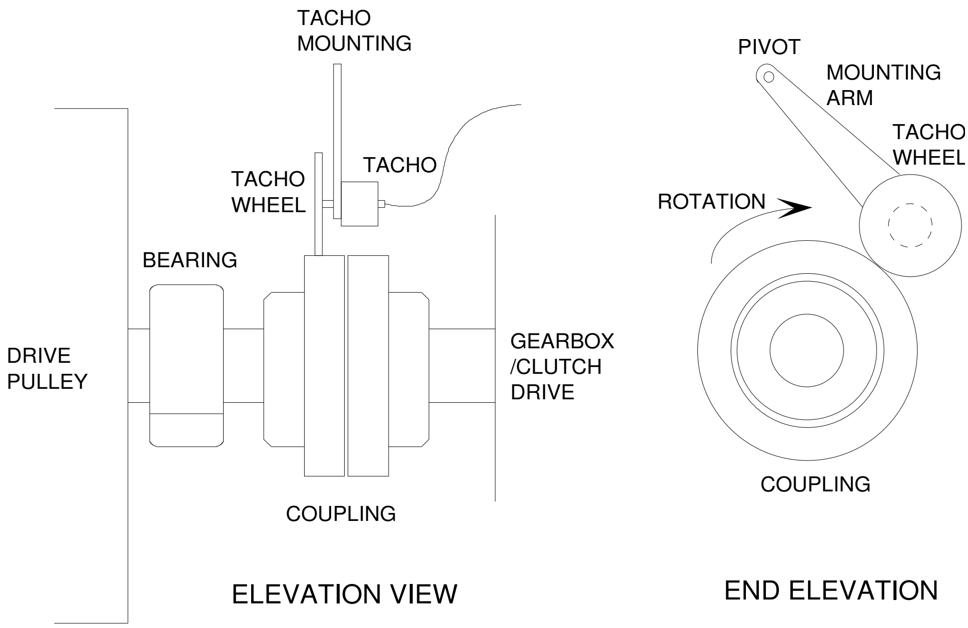


figure 24

Encoders - provide a frequency proportional to speed and are used in conjunction with a frequency to voltage or current converter to provide the speed feed back signal suitable for a PLC. They work on the principle of a clear disk with fine lines passing between a light source and a receiver. This signal is then amplified to provide an output square wave whose frequency is proportional to speed. A separate module then takes this square wave input and converts the signal to an analog voltage or analog current suitable for input to a PLC. Their mounting is the same as that illustrated in figure 24.

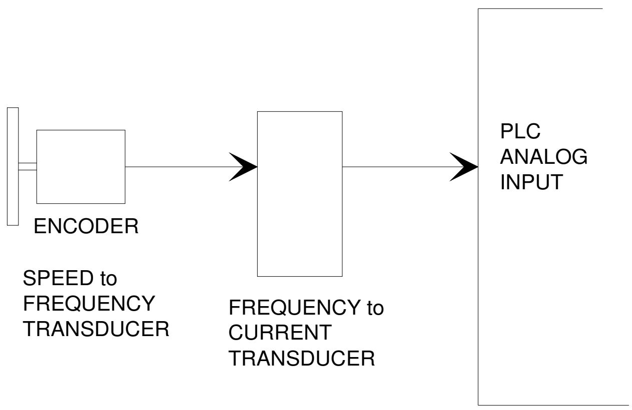


figure 25

Figure 25 shows the arrangement necessary for use of an encoder for monitoring conveyor speed.

Proximity detectors - when used in conjunction with slotted wheels on rotating shafts, provide a frequency proportional to speed. Like encoders, they need a frequency to voltage or current transducer to interface to a PLC.

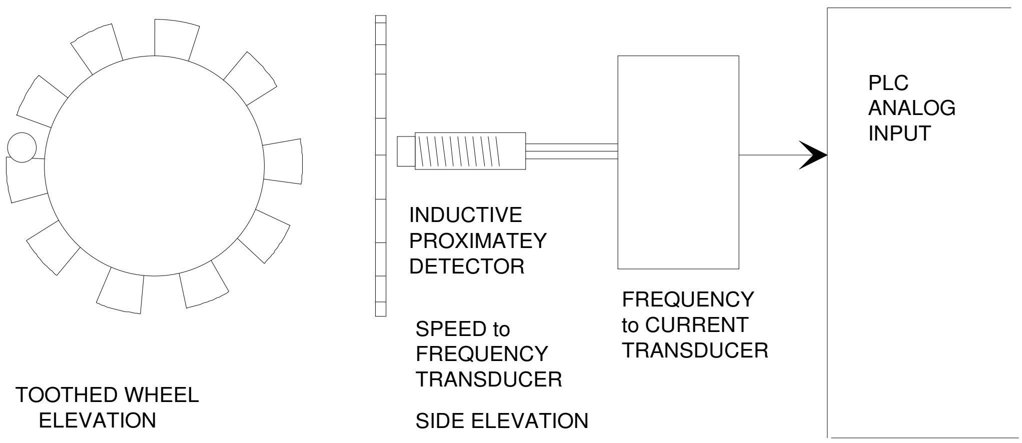
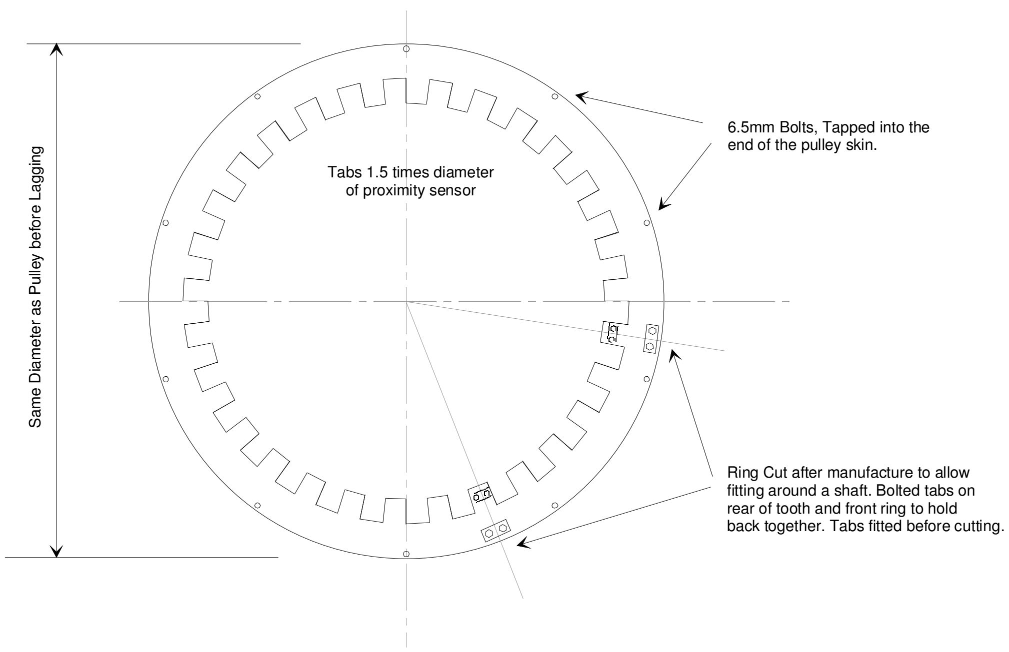


Figure 26

The above plate configuration is sometimes subject to plate buckeling due to rough handling. This gives a surging speed feedback. A more reliable method is shown in the figure below, where the outer steel rim of a pulley provides the support for the teeth.

CNC Laser Cut (minimise warping) from 6mm mild steel (8mm would be stiffer)



HYDRAULIC PRESSURE CONTROL OUTPUT

Control of the clutches are achieved through a hydraulic proportional valve. These valves provide an output hydraulic pressure that is proportional to current flow through their coils. The current flow normally lies in the range of 0 to 500ma and 0 to 1.6A. These values are outside the normal PLC output card's drive ability and so a booster amplifier must be used. It is desirable for the booster card to have the following features :-

1) Ability for manual control over the full range for commissioning and emergency conditions.

2) Closed loop current control of the drive stage to negate drift due to temperature variations in the coil.

3) Fast response to change with no built in ramps or time lags. Additional lags make PLC PID tuning more difficult.

4) Standard 4 to 20ma control signal input.

TYPICAL OPERATING SEQUENCE

The normal starting sequence for a clutch system is as follows :-

1) A sequence start command is given to the conveyor drive-head.

2) The Drive head performs it's pre-start checks and then commands a start to the loop takeup winch and the clutch control.

3) The clutch system starts it's hydraulic pump and ensures that lubrication is O.K. The winch starts and applies starting tension to the conveyor.

4) Once the clutch system and the winch system indicate they have completed their pre-start and there are no fault conditions, the drive head motor start is enabled.

5) The drive-head starts the main motors DOL on no load in an appropriate sequence.

6) Once the drive head motors have started and settled (approx 3secs) a pressure to over come the springs and just touch the clutch pack plates is applied. A small time delay is used to allow the applied pressure to fill the thrust piston chamber. The cooling fans are turned on for the duration of the start.

7) The pressure is now gradually increased drawing more motor current. This stage is called the torque ramp as the motor torque is increased until the conveyor begins to move.

8) The control system now switches in which ever ramping control is used.

9) Once the conveyor has reached full speed the full speed control is switched in.

FAULT MONITORING

The following fault conditions must be monitored and stop the conveyor should they occur :-

1) Loss of hydraulic pump. The cooling and lubrication flow will be lost causing damage to the clutch.

2) Excess oil temperature. Oil that exceeds 100 degrees Celsius looses its lubricating properties and will permanently damage the clutch.

3) Broken hose or damaged oil seals. A broken hose may be monitored by oil levels dropping in the reservoir tank, loss of lubrication pressure or the inability to control the clutch properly.

4) Dirty or blocked oil filter. Filters that are blocked will bypass dirt into the system. This will eventually cause problems in the proportional control valve. Although it is not necessary to stop the conveyor, the fault should be remedied quickly.

5) Belt slip. Belt slip should be monitored on each driving pulley. Even the smallest amount of slip will cause heating and damage both belt and pulley lagging and provide a fire hazard.

6) Loss of transducer signals. The loss of motor current, speed or tension feedback will caused an uncontrolled response by the PID closed loop system. These signals should be monitored and the conveyor tripped if any are lost or out of range.

OVERCOMMING PID OSCILATION PROBLEMS

CAUSES OF OSCILATION

ELASTICITY

PID algorithms have proven to be a successful control technique over many years. Unfortunately they have a weakness in that they do not perform well on elastic loads. The problem arises because as an adjustment to the output is stored as elastic energy in the load. The PID would have expected to see some feedback change after it modified the output, but this has not occurred. The PID therefore makes another modification in output , and then another until it sees a change in feedback. Eventuall the stored elastic energy is released, which then causes an overshoot of the load value. The PID see this overshoot and compensates by driving the output in the opposite direction. Because of the elastic nature of the load, the change is again not reflected in the feedback and so it compensates again. This lag in feedback can cause large oscillations in the control system. The typical response of the Technician or Engineer is to lower the gain of the PID so that it does not over re-act. This of course provides a very soft control system where the result may be erroneous from the set point by a unacceptable value.

LARGE VARIATIONS IN LOAD CONDITIONS

There are variations of control requirements between an empty conveyor and a fully loaded conveyor. Ratios of around 1:4 are found on flat conveyor systems, while ratios as high as 1:15 are common on high lift conveyors. A PID control algorithm makes a certain amount of output change based on a certain error between the required setpoint and the actual feedback. The actual value is governed by the system gain, which is determined during commissioning. However, the response to an error should be less for an empty conveyor and more for a fully loaded conveyor. The bigger the difference between no load and full load, the harder it is to find the right compromise for the tuning.

PROCESS DISTURBANCES FROM ANCILIARY EQUIPMENT

In certain installations, gravity devices are unsuitable for tensioning conveyors. In these circumstances electro/mechanical devices take up the slack in the conveyor caused by elastic stretch in the belting during starting period and load changes. Generally devices that provide proportional speed to tension change control, do not cause problems. However devices that provide a fixed speed tension adjustment, pulse in operation and can cause problems in the closed loop circuitry. This pulsed response to error causes a pulse in the speed control feedback signal, for which the PID algorithm can over respond.

NON LINEAR RESPONSE FROM TRANSMISSION SYSTEM

BOSS clutches and certain Fluid couplings have non-linear response to control over their entire operating range. With a BOSS coupling the required pressure to maintain torque begins roll off as the relative plate speed between input and output drops below 10% of full slip speed. Many Fluid couplings have non-linear scoop position to transmitted torque relationships. These are generally represented in graphs supplied by the manufacturer.

TECHNIQUES FOR LIMITING CONTROL SYSTEM OSCILATIONS

INPUT ERROR LIMITING

This technique involves limiting the size of the error fed to the PID algorithm by adjusting the set point closer to the feedback value if the error becomes too great. This technique is popular with drive head control where unforeseen outside influences, such as jammed belting, erratic tension control or changing load conditions. (e.g. a heavy block of material passing over an undulating horizontal profile)

RATE OF CHANGE LIMITING

In this case a rate change limiter is fitted between the output of the PID and the actual output to the control value. In practice it is an integrator, but implementation in PLC code can be as simple as a periodic fixed add or subtract to increase or decrease the output control based on the result of the PID and the current value of the output. This is done in small steps over a period of time, rather than a single large step. This technique is popular with tripper drive control.

VARIABLE PID GAIN CONTROL

Either the applied torque or applied power from the drive motors is used to modify the gain of the PID. A proportionally higher gain is used for heavy loads and a proportionally lower gain is used for lighter loads. This technique is popular when there is a large differential between no load and full load.

INTEGER MATH CONTROL

This method uses a much simpler algorithm than a PID. On a regular time tick, usually one or two seconds, the actual speed is compared to the required speed. An error value is calculated and a portion of this error added to the output control. The portion of the error that is added provides a gain control, while the rate of sample provides an integral control. This technique provides a softer response to error than standard PID control.

LOOKUP TABLE LINEARISATION

This technique provides a simple method for overcoming non-linear relationships between control signal and actual applied torque. It usually requires passing the result of the PID algorithm result through a lookup table modifier before it is passed to the output controller. This might be applied pressure in a BOSS control circuit or a dip compensation for scoop position in a fluid coupling.

In very difficult control systems, a lookup table that converts motor current to applied motor torque can remove offsets that create problems for the control system.

SWEET SPOT LIMITING

In this method, the output of the speed or acceleration PID is clamped to reasonable limits based on typical start knowledge. For example once a conveyor is fully stretched and moving at say 10% to 15% speed, you know that you will not require less than the current value of motor current to accelerate the conveyor to full speed. This becomes the minimum output of the speed or acceleration PID during the ramp. You also know that you will not need more than 1.3 to 1.35 times this motor current value to accelerate to full speed. This becomes the maximum output of the speed or acceleration PID during the ramp. This method also becomes a safety relief if a speed feedback transducer fails during the ramp.

Clamping can be achieved by directly overriding the output stage of the PID or switching the PID to manual for a period will ever the output is outside the sweet spot limits and holding either the minimum or maximum value as required,