DEVELOPMENTS IN AUSTRALIAN LONGWALL BELT CONVEYORS: ELECTRONIC CONTROLS

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Synopsis

The retreating longwall maingate conveyor belt presents unique design complexity based on an ever changing geometry. Upward movements in production targets and efficiency levels have forced more demanding installation designs.

The trend has been to introduce equipment of increasing complexity and sophistication in order to accommodate these demands, however, the application of adaptive learning controls to existing, less complex devices can produce more simple and reliable solutions. Adaptive control systems reduce the skill demands on operators and allow improved performance from the conveyor over changing conditions.

Examples are presented with the mechanics and adaptive strategy explained.

1.0 INTRODUCTION

During the past several years in Australia, as elsewhere in the coal mining world, there has been significant attention by both coal mining operators and the major engineering suppliers towards system designs which reduce both the capital and operating costs and improve the reliability and performance of retreat longwall panel belt conveyors.

The conveyor belt application in a retreating longwall installation presents several unique operational parameters to be considered at the design stage. The most obvious and one of the most significant design features of the retreating panel conveyor is the ever changing length and associated change in overall lift or fall due to seam grade. In such a conveyor, not only does the effects of varying load need to be considered but also the effect of varying geometry.

The compound effects of load and geometry changes during the operation of the conveyor can have significant impact on the following parameters;

* Demand power
* Belt tensions
* Braking requirements
* Belt take up operation
* Start characteristics

Changes in some of these parameters may, in many cases, be of little relevance particularly in simple design cases or shorter retreat lengths, however, the development of more demanding longwall blocks is making many of these parameters of crucial importance to the conveyor belt designer. The greater application of booster or intermediate drives is allowing the creation of longwall blocks of greater length. In turn this increases the probability of multiple section undulations in the belt length with various incline and decline sections. Not only is the analysis and resultant design made more complicated by the potential combinations of inclines and declines loaded, but the conveyor geometry, including drive locations is not fixed because of the retreating condition.

The trend in installing these conveyors has been to develop more and more elaborate equipment with greater ultimate performance in order to handle the wide range of operating conditions which can be encountered.

An example of this increasing complexity is sophisticated soft start devices such as hydro-viscous clutches and scoop couplings.

The down side of such an approach is that increasing complexity in the equipment can lead to greater demands on service, maintenance and operator skills. The equipment becomes so specialised that only specialised service personnel can trouble shoot or repair the equipment. This is of particular concern when the down time on the conveyor has a major impact on production and it is usually the case that such sophisticated equipment is installed on the main belt systems.

Alternatively, by applying adaptive learning control systems relatively simple and proven equipment can be used. Rather than having equipment immediately capable of handling a wide range of worst cases, the control system can modify performance to suit changing conditions.

A prerequisite to installing high performance conveyors is to perform a thorough analysis to predict conditions, however we have all found from experience that even once the best pre-installation design is undertaken it is invaluable to employ components and systems which can be readily adapted to changed or unexpected conditions. The logical extension to this process is to develop equipment which not only can be adapted to altering conditions but which automatically adapts, thus relieving the operator of the need to constantly assess performance, monitor changing conveyor conditions and make specialised design decisions on appropriate actions.

This paper presents an overview of the concept of adaptive learning as applied to conveyor belt systems and two recent developments we have undertaken in such automatic adaptive systems in Australia.

2.0 ADAPTIVE LEARNING

2.1 The Adaptive Learning Concept

In order for a control system to have adaptive capabilities it must have the following features or components;

i) Monitoring System
A means of measuring or detecting external parameters such as belt tension, acceleration, velocity and time.

ii) Control Algorithm
A generalised set of rules which define desired performance or response (output of the control system).

These concepts are not new and would be familiar to anyone who has contact with automatic control devices. The interest lies in the types of parameters which can be measured in a belt conveyor system and the actively changing information which can be determined from these measurements. Finally the usefulness of this process relates to the way in which this information can be used by the equipment to modify operation accordingly.

2.2 Possible Adaptive Scenarios

A large number of conveyor systems exist throughout the world which already monitor basic operational parameters such as belt speed and belt tension. These monitored variables are typically used to control start up and belt take up, however from relatively simple measurements far more extensive information can be determined. More detailed data allows more sophisticated assessment of conveyor operation by the control system and thus better modification (or adaption) of the performance of the controlled device.

We have developed systems which have the capacity to establish and use parameters such as;

Conveyor length in a retreating longwall installation.
System (belt) elasticity.
Belt shock wave velocity.
Drive performance at start.
Take up winch overshoot and error.
Take up hysteresis.

In order to explain the application of these concepts two examples are presented below.

3.0 AN ADAPTIVE WINCH SYSTEM

3.1 Background

Belt tensioning systems for longwall belt conveyors have received much attention in recent years resulting in major advances in performance. One example is the use of hydraulic "mooring" winches which were first applied in Australia some ten years ago, refined over several years and subsequently they found application elsewhere in the world. A similar example is the eddy current drive based winch which was first developed in Australia by this writer in 1986 and subsequently adopted by other suppliers and users. Thus in the quest for take up performance several alternatives have been developed, some with success and unfortunately some with a marked lack of success.

The major features which limited successful application were;

> Complexity resulting in a demand for skilled trouble shooting and service.

> Equipment life cost - capital, operating and service costs.

> Poor response time unable to track dynamic shock waves.

> Hysteresis due to inherent winch characteristics in addition to sheave frictions, rope flexure etc.

> Instability of control leading to hunting.

> Inability to release high strain energy conditions safely.

> Inability to provide differing tension levels suitable to the conveyor mode - running, starting, stopping, belt extraction.

Each take up system in use exhibited one or more of these limitations. For example eddy current winches suffer from hysteresis and inertial overshoot whilst switched motor winches have limitations on speed without hunting, relying on large deadband to stabilise control.

None were capable of assessing changing conveyor conditions and automatically altering performance.

3.2 Winch Design

The winch design brief was to develop a device which overcame all of the earlier limitations and in addition take advantage of the wide application and flexibility of PLC based control systems using an adaptive control algorithm.

Controlled release of high strain energy conditions was also identified as an important factor. Long maingate conveyors can develop elastic strain energy in excess of 1.5 Megajoules during aborted or full load stops. This represents considerable energy. It is sufficient to accelerate a 10 tonne pulley carriage to 17 meters/second.

Dissipated over only 10 seconds it represents a power flow of 150 kW and such energy transfers have been the cause of catastrophic failures in eddy current and hydraulic winches. Thus a means was required for releasing this energy in a controlled manner.

The winch system comprises;

Mechanical drive system,
PLC based control package and
Tension and motion feedback package.

The take up winch has the facility to automatically assess the conveyor in which it is installed for such parameters as elasticity, shock wave velocity and hysteresis and adjust its performance to suit. Self diagnostics and self commissioning facilities can be added.

In order to explain how these features have been developed we must briefly consider the operation of each of the system parts.

3.3 Winch Mechanical Drive

The drive unit comprises a pair of engaging clutches, a one way clutch and a regenerative coupling shaft. The package is typically powered by a 30 kW motor and coupled to a high efficiency gear reducer which in turn drives the winch drum. Hence the mechanical system is quite simple.

Figure 1 provides a schematic of the winch system components.
Figure 2 is a diagrammatical representation of the drive train.

When the belt tension lies within a setpoint range as reported by the feedback unit the drive is in its neutral or powered down state. The motor is uncoupled and runs at no load.

If low tension is detected the winch will engage and wind until setpoint is reached. If high tension is detected the winch will disengage part of the drive train and pay out until the tension is corrected. The key to the operation of the drive is the very rapid rate at which it can perform these operations. The drive is able to accelerate from rest to full speed in 0.25 seconds and stop in a similar time. By combining this response rate with digital control the unit can either track rapid belt stretch changes such as at start up or make fine corrections to slow tension movements.

Conditions of high energy pay out are controlled by including a shaft which couples the output shaft and motor in such a way that if the output shaft speed during pay out exceeds the motor synchronous speed, regenerative braking is provided by the motor.

3.4 Tension and Motion Feedback

Installed within the winch drive are several proximity sensors which detect motion within the drive. Signals from these are sent direct to the PLC. The signals are used to detect;

Direction of rotation of the motor,
Clutch slip outside design levels and
Gross motion of the drive such as number of turns.

Motor direction is checked to ensure correct onase termination of the motor during installation.

Clutch slip detection forms part of the protection systems. The gross motion detection forms part of the adaptive learning algorithm and will be detailed later.

Belt tension is monitored via strain gauge load cells fitted at both the winch rope anchor and a fixed pulley. The feed back from both is compared and the relationship is used to make judgements on the take up system during operation. This "dual comparative" feedback allows detection of sheave friction or seizure, rope break or pulley friction.

3.5 PLC Control Package

The control logic for the system can be loaded into any major PLC hardware system and requires a CPU, EPROM, digital I/O card and Analogue I/O card.

The entire control, monitoring and adaptive learning facility resides in the PLC software.

Critical winch conditions are monitored and stored in a stack. These include clutch slip, motor speed, fault alarms, winding activity and belt tension.

Monitored data can be communicated via data highway to conveyor starter or a central control facility. Alternatively, following a shut down fault, the control can be placed in REPLAY mode and the winch activity for say 10 minutes preceding the fault can be simulated at the controller to enable investigation of the failure or fault tracing. Thus unskilled operators can visualise the winch activities prior to a fault and help identify the problem.

3.6 Adaptive Learning

The key advance of the winch system is the ability to evaluate the conveyor characteristics and its own performance and alter control appropriately.

Consider Figure 3, which presents a theoretical tensioning cycle for the winch. The control system can be placed in "commissioning" or "learning" mode whereby it winds the winch from one tension to another in the generally expected range of operation. The motion and tension detection system is used by the PLC to establish from this simple test two key parameters, system elasticity and hysteresis.

System Elasticity

The number of pulses or turns of drive activity to change the tension from say 2 to 5 ton provides a measure of the elasticity of that belt and conveyor installation. For example a long, elastic conveyor may record 3000 pulses per 3 ton tension change or 1000 pulses/ton and the same conveyor belt, but shorter may record 500 pulses/ton. Thus the controller can measure elasticity of the installation and determine suitable parameters for the control algorithm such as deadband, dwell time etc. If during operation the system detects changes in that elasticity it can modify its control accordingly.

An application example of this is a retreating longwall panel conveyor. Initial installation is likely to be long and elastic, stretch rates at start will be high and the conveyor's sensitivity to take up trolley movement low. Thus the suitable winch response is rapid but with longer dwell periods to establish tension trends. As the conveyor retreats, the belt system will become stiffer or less elastic which can be automatically detected and the response parameters modified by the controller to avoid instability or excessive motion in the take up.

Hysteresis

The data from the elasticity measurement routine of winding between tensions can further be used to establish hysteresis in the take up. For example 3000 pulses may be detected when winding UP from 2 to 5 ton and 2900 pulses when winding DOWN from 5 to 2 ton. Such information can be used to refine the performance depending on which direction the winch is going or more simply can be used as an alarm flag to the operator particularly if hysteresis increases, which may indicate a deterioration in the take up mechanics, trolley or pulleys.

Conveyor Length

It is possible to define the elasticity of the actual belt being used as an operator input and for the control system to estimate the conveyor length based on the preceding tension/travel measurement.

Overshoot Correction

A second test the controller can perform is to measure the over shoot of the drive mechanism and correct accordingly. Consider the case where the winch is directed to pay out to a particular tension say 2 ton and when shut down, settles at 1.9 ton, the overshoot of 0.1 ton caused by the lag in control. Such overshoot is more likely to develop on a retreating conveyor when the belt is short and stiffer. The control system can measure this overshoot and correct the control algorithm so that it begins the shutdown 0.1 ton early, thus stoping exactly on the desired tension.

Referring to figure 4, the operation of the winch is plotted against a driving function or setpoint during a load test. The rope load during the test was 5 ton with an impact load of 10 ton. The plot shows various changes to the setpoint such as gradual ramp, steady state and rapid step changes.

The gradual ramp of set point is tracked by the winch in sequential steps of winding or paying out. Close inspection of the plot at the large step down change in set point indicates a short duration acceleration until full pay out speed is reached followed by a controlled reduction at maximum speed which is being limited by the regenerative braking facility.

4.0 THE VFT CONTROLLER
(Variable Fluid coupling Torque)

4.1 Background

The simple, constant fill traction coupling has been widely applied in conveyor belt systems for many years. Its advantages of low cost, reliability and simple operation made it an acceptable solution for many applications. In recent years as belt capacities, installed length and drive powers have increased the limitations of the traction coupling have reduced its acceptance. Key limitations were high start torques, varying start torque during acceleration and the inability to vary the torque characteristics other than manually correcting the oil fill level.

The growing demands on conveyors required more sophisticated control over the start in order to limit belt tensions and acceleration.

Improvements to the fluid coupling have included delay filling chambers, scoop trim of the fluid level and more recent open circuit fluid control.

Alternative methods of start control have been developed like hydroviscous clutch. These sophisticated closed loop control drives can provide very soft start characteristics in addition to load sharing, however they result in complex mechanical and hydraulic systems.

Research was undertaken on the concept of controlling traction couplings by electronic means resulting in the development of a control system which addresses some of the characteristic limitations of the fluid coupling.

4.2 The VFT Concept

In its simplest form the "ideal" start characteristics provides a flat torque/speed response during acceleration. A constant torque will simply provide constant acceleration. Obviously more sophisticated start algorithms can and should be applied in practice, however this reduced form provides a sufficient base for comparison.

Referring to figure 5, the output torque of a fluid coupling will vary with output speed. The plot represents a typical curve for a unsophisticated, constant fill coupling under start testing.

Previous efforts aimed at improving fluid coupling performance have centred on either improving the chamber design or modifying the fluid volume in the working chamber during start with techniques such as delay fill bleed or scoop trim.

An area which has not been fully exploited is the fluid coupling's sensitivity to input speed.

The output torque is related to the input speed squared thus;

$$\mathbf{Tout} = \mathbf{f(Win)^2}$$

where;

Tout = Coupling output torque

Win = Coupling input speed (motor speed)

Thus changes in the motor speed over a narrow range during acceleration of the coupling can produce significant changes in the output torque for a given output speed.

Speed change in a squirrel cage motor is normally associated with frequency control, however the solid state circuits necessary to achieve this at typical motor powers are relatively costly. Due to the range of control which is required a method can be employed which utilises voltage control on the motor supply employing SCR stacks. These units are cost effective. Altering the supply voltage shifts the motor torque/speed curve such that the operating speed for a given torque is reduced.

The use of motor voltage control in conjunction with traction couplings is not unique, having been employed both in South Africa and Australia in the past. The difference is that in the past the system has been open loop control and the full benefit has not been gained. Earlier systems basically summed the performance of the SCR starter and the traction coupling. By employing a closed loop control and applying an adaptive algorithm far superior performance can be achieved.

4.3 VFT Execution

Drive torque can be measured by traditional means such as a load cell on the drive reaction arm, or alternatively the belt acceleration can be monitored by speed sensing. This feedback can be used in a closed loop control which drives the SCR voltage output in response to an error between actual and setpoint torque or acceleration.

Thus during start up, the motor is initially started and rapidly approaches full load speed. As the fluid coupling torque builds to a point exceeding the desired setpoint, the voltage to the motor is reduced over a small range. This in turn shifts the motor speed/torque curve resulting in a slightly lower motor speed and thus a limited developed torque at the fluid coupling.

Fluid coupling heating becomes a primary function of the mass accelerated rather than the time taken. By developing a flat torque curve from the traction coupling/motor combination during start a lower force for a longer period of acceleration is equivalent to a high force for a short acceleration.

Refer to figure 6 which is a plot of output torque vs time for the same traction coupling used in figure 5 but with the VFT control system operating. As can be seen, the torque/speed curve of the fluid coupling is flattened to better approximate the ideal constant torque figure.

4.4 VFT Adaptive Learning

The SCR stacks within the VFT are controlled by an algorithm coded into a PLC. The algorithm is essentially a PID control loop on the error established between the set point torque or setpoint acceleration rate and that reported by the feedback circuit.

Each time the controller operates and the conveyor is started, PID loop alters the control parameters to minimise the setpoint error. Thus the controller improves performance each start and can adapt to a gradually changing environment such as a retreating maingate conveyor. The result in an application's sense is that consistent start characteristics are maintained over a larger range of operating conditions than that which could be achieved with traditional fluid couplings.

5.0 CONCLUSIONS

Conveyor equipment with adaptive learning capacity is relatively new, however it provides an important field of development in conveyor systems. The ever increasing economic pressures on mining operations means that methods of improving performance, reducing operator demands and increasing reliability must be fully exploited.

Particularly important is the potential to avoid the increasing complexity of conveyor systems in order to extend performance. Adaptive learning systems applied to conveyors provides a means to improving performance without substantially increasing equipment complexity.

It is hoped that the developments presented in this paper generate further interest in this field by both equipment designers and mining operators.