WHY USE ELECTRONIC VARIABLE SPEED DRIVES ON CONVEYOR APPLICATIONS

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INTRODUCTION

As customer demands for lower prices, increased quality and shorter delivery times are becoming more and more significant, manufacturers have to look seriously at their manufacturing techniques and implement systems which satisfy these demands in the most economical way. Failure to do this will eventually lead to business failure. The electronic variable speed drive is challenging more and more traditional methods and solutions used in the manufacturing and mining industries and are being regarded as a serious alternative with its inherent flexibility as a very attractive feature. The methods used in controlling the various conveyors used in industry and more particularly those in the mining industry have also fallen under the spotlight during the last five years. This paper investigates the traditional and historical methods of controlling the start up and stopping of conveyor belts (with obvious emphasis on the longer belts) and introduces the electronic variable speed drive as the solution to overcome all the shortcomings of the historical solutions.

IDEAL STARTING AND STOPPING REGIME

The ideal starting and stopping regime of a conveyor includes for the accurate control of drive acceleration/deceleration and for accurate control of jerk or rate of change of acceleration. Both these parameters should be controlled accurately below a certain maximum value, so that the belt tension rating can be minimised, the drive system size maybe minimised and the most economic conveyor system may be selected. The torque - speed curve of a standard conveyor can be considered to be characterised by a constant torque requirement over the total speed range with a characteristic increase in torque required to break away the conveyor from standstill. The idea! torque-time curve for a standard conveyor is characterised by the slow application of torque at start until the breakaway point is reached.

The ideal speed-time curve is characterised by the typical S curve shape. This shape is constant irrespective of the loading of the conveyor, as it is the dynamics of the conveyor and not the load that prescribes the parameters of the S type speed time curve.

D.O.L. STARTED SQUIRREL CAGE MOTOR

The first method that has been employed in controlling the squirrel cage motor that is coupled directly to the head pulley via a suitable gearbox is the direct on line (D.O.L) method.

This is the simplest way to start a squirrel cage motor. In such cases the only starting equipment needed, will be a direct on line starter. To understand the advantages and disadvantages of this method, the torque-speed curve and the corresponding current-speed curve of a typical squirrel cage motor should be studied - see figure no. 1.

The first parameter to be evaluated is the breakaway torque or locked rotor torque Ts/Tn. This is the torque developed by the motor at switch on. For a standard squirrel cage LV motor manufactured according to I EC 34 standards the value of this parameter can range from 2,3 times rated full load torque for small 4 pole motors having a power in the region of 75kW to 1,1 times rated full load torque for large 4 pole motors having a power in the region of 630kW. In the case of 6 pole motors the range for this parameter varies from 2,4 to 1,3 while for 8 pole motors the range is 1,4 to 1,7 times rated full load torque. The value of these parameters would also vary from manufacturer to manufacturer. The second parameter to be evaluated is the breakdown torque or pull out torque Tmax/Tn. This is the maximum torque that the motor can develop assuming rated voltage is applied to the motor terminals. The value of this parameter varies between 2,5 times rated torque for small 4 pole motors to 2,8 times for large 4 pole motors. For six pole motors this parameter ranges from 3,0 to 2,7 times and 2,4 to 3,0 times for 8 pole motors. Again this parameter will vary from motor manufacturer to manufacturer and also on whether the motor is designed for operation in non hazardous areas or not.

Thus it is evident that on switch on, a torque step is applied to the conveyor. This implies a very high rate of change of acceleration or jerk, and as the magnitude of this torque step is significantly larger than rated full load torque of the motor, the initial acceleration of the conveyor belt will be high as well, and may well excite certain resonances in the conveyor belt. As the motor speed increases, the developed torque also increases until the pull out torque peak is reached whereafter the developed motor torque decreases until the net accelerating torque is reduced to zero. Thus the criteria of controlled small values of jerk cannot be realised. The other problem is that long acceleration times cannot be tolerated by the squirrel cage motor. At switch on the starting current of a squirrel cage motor is in the region of 7 times full load current, decreasing to 3,5 times when the motor has accelerated to the speed corresponding to the breakdown torque and finally decreasing to full load current when rated speed and load is obtained. Thus as the starting current of a squirrel cage motor is significantly higher than rated current, an excessively long starting period causes a harmful temperature rise in the motor. Each motor is given a permitted starting time parameter. For a 75kW 4 pole motor the permitted starting time is 18 seconds while for a 500kW 4 pole motor the permitted starting time is 20 seconds. This time is significantly short and therefore the maximum conveyor length for this type of starting method is correspondingly short.

REDUCED VOLTAGE STARTER AND SQUIRREL CAGE MOTOR

The second type of starting method that has been employed is the mechanical reduced stator voltage starter. This form of starting method can employ star/delta or reactor or stator resistor starting equipment. The effect of this equipment is to reduce the applied voltage to the motor terminals on switch on. The torque that the motor develops under this condition is approximately proportional to the square of the applied voltage. In the case of the star/delta method the starting torque is reduced to one third of the D.O.L. value while the starting current is also reduced to one third of the D.O.L. value.

Another variant of this type of starter is one which employs resistance in the stator circuit to reduce the applied voltage and hence the switch on torque and starting current. The benefit of using these variants, is that the applied voltage at switch on can be set at any level less than the supply voltage and that multiple units can be used and switched in at appropriate times, in an attempt to obtain the gradual application of torque at switch on.

The major difference between the mechanical reduced stator voltage starter and the electronic versions is that the starting current can be adjusted to any level. In some of the more sophisticated units the starting current can be ramped at a particular rate, thus fulfilling the controlled ramping of the torque requirement.

SLIPRING MOTOR AND ASSOCIATED CONTROLLER

The third type of starting method that has been employed is the slipring motor and the associated rotor control equipment. The feature of the slipring motor is that the rotor characteristics can be varied externally so that the torque developed by the motor can be controlled from standstill to rated speed and that the heat losses are dissipated externally. The major disadvantage of this method is the cost and poor availability of low voltage slipring motors. Rotor control equipment for conveyor motors normally include for grid resistors switched in various steps to provide the required resistance. In order to reduce the size of the torque step when switching occurs many steps are provided. This method allows the control of the torque developed to range from very low values to 250% of rated torque.

A further development utilises the electronic soft starter, the slipring motor and two or three grid resistors steps switched by contactors to obtain a smooth generation of torque over the subsynchronous speed range.

FLUID COUPLINGS

The fourth type of starting method that has been employed is the mechanical soft starter or variable speed unit situated between the motor and the gearbox. These units work on the principle of the torque transmitted by the coupling is controlled by the quantity of fluid within a certain working chamber within the unit. At switch on of the motor there is no or little fluid in this chamber and therefore very little torque is transmitted by the coupling. This allows the motor to start and attain rated speed under a no load condition. As fluid is slowly introduced into this chamber, so the torque transmission increases at a similar rate. Thus the criteria for ideal starting of a conveyor, namely slow application of torque (slow acceleration) and smooth application of torque (minimise jerk) are fulfilled. The fluid drains from the working chamber when the coupling is brought to rest to enable a restart. If an externally variable control mechanism is employed to control the filling of the working chamber while it drains through a nozzle at a predetermined rate, then the torque transmission can be controlled. With the application of suitable automation equipment, variable speed operation is possible as well as load sharing between multiple drives. If the motor in this application is connected to a weak supply network, then a reduced voltage starter can be employed to reduce the starting current drawn to more acceptable levels.

ELECTRONIC VARIABLE SPEED DRIVES

The fifth type of starting method that has been successfully employed, is the electronic variable speed drive. The type of drive that has been employed is the voltage source inverter that uses the vector control PWM control philosophy, or the more recent technology development that uses the direct torque control philosophy. These drives are able to overcome all the short comings of the other type of drives or starting equipment that have been described earlier.

Superior Controllability

These drives are able to control the torque developed by the motor over the entire speed range. Thus the main criteria of minimising the rate of change of acceleration to prevent the excitation of any mechanical resonances and minimising the acceleration at any speed to control the maximum tension in the conveyor belt are easily fulfilled within a tight tolerance. This permits the various margins of safety to be evaluated so that the optimum mechanical design of the conveyor can be reliably implemented. These drives also permit the motor to operate at super synchronous speeds so that the optimum choice of motor and gearbox is possible. This feature does not detract from the torque and speed control capabilities of the drive.

Another feature that could be utilised is the capability of reversible operation. The electronic variable speed drive can be made reversible by setting a certain parameter to allow this operation and by setting a certain digital input the direction of rotation may be reversed. This feature could have major cost saving implications in certain application of conveyors.

Overland conveyors can be of one of two types namely a predominantly uphill conveyor or a predominantly downhill conveyor. The uphill conveyor does not present any new problems from a control aspect while with the downhill conveyor the issue of braking has to be investigated. The electronic variable speed drives are capable of braking a load on a continuous basis. This is done by selecting the appropriate line regeneration incoming unit option for the drive. This unit allows the flow of energy from the DC busbar back into the supply network. Various switching technologies such as thyristor or IGBT are used in this unit; the selection of which is dependent on the quality of supply. This method of braking ensures that, as much energy is pumped back into the supply and thus helping to reduce the overall energy costs for the operation.

Even though the drive will perform the braking function for all normal operations the correctly sized mechanical brake will still have to be provided to cater for the conditions when there is a disconnection from the main power supply.
In multiple drive pulley conveyor designs one of the biggest control issues to be realised is equal load sharing between the various pulleys. Through the necessary master-follower software resident in the drive hardware this function is readily implemented. One of the drives is operated in speed control mode while the others are operated in torque control. The torque reference signal for these drives are derived from the torque signal in the speed controlled drive.

The beauty of having this special master-follower software resident in the drive is that no extra automation equipment and associated software engineering is required. These master- follower macros are a standard option for the drive and therefore have been thoroughly tested and proven in many applications.

The electronic variable speed drive can also communicate with overriding PLC/DCS control systems by means of a serial link. As there are so many field busses available drive manufacturers have been forced to provide the necessary interfaces for the more common protocols.

Another feature that the electronic variable speed drive provides, especially those using the direct torque control principle, is the instantaneous restart feature after an aborted start or a power outage. There are no limits to the number of starts per hour if the current limit is set to rated full load current.

Thus there are no restart delays and the conveyor can also be restarted while still in motion without compromising the ideal conveyor starting requirements. The same cannot be said with the fluid coupling solution.

Reduced Maintenance

Traditionally conveyors are operated at a fixed speed. This is mainly due to the type of starting equipment that has been utilised. The electronic variable speed drive allows the conveyor belt to be operated at any desired speed. Thus the conveyor could be operated at a constant loading and would therefore operate at reduced speed when lightly loaded. This would lead to reduced wear and consequent reduced maintenance costs.

The electronic variable speed drive and squirrel cage motor combination has very few moving parts: basically the motor and the stack cooling fan motor. As there are few wearing parts, so only annual maintenance is required.

Belt slip is reduced to zero as the electronic variable speed drive controls the torque very accurately, has an adjustable maximum torque limit and there are no torque steps applied to the conveyor. This situation will lead to a substantial decrease in the number of splices that have to be performed during the year. This leads to reduced maintenance and reduced production downtime.

Better Reliability

As the electronic variable speed drive has few moving or wearing parts the reliability of the installation is greatly enhanced. Typical figures of mean time between failures for an electronic variable speed drive is in excess of sixteen years and the mean time to repair is typically less than 1,5 hours. These figures are superior to those of fluid couplings. As the conveyor belt is not subject to tension transients or excessive tension the belt should last a lot longer.

Reduced Capital Costs

Due to superior controllability of the electronic variable speed drives especially those employing direct torque control, factors of safety can be reduced when determining the tension rating of the conveyor belt.

The motor used with an electronic variable speed drive is a standard squirrel cage motor. The use of an electronic variable speed drive with a standard squirrel cage motor does not demand a larger motor frame size than the motor used with the equivalent mechanical fluid coupling if the motor is to be operated at rated speed. If the conveyor needs to be operated at full load for long periods of time at very slow speed, then the motor would have to be fitted with a forced ventilation system. The drive end bearing of the motor could be a standard ball bearing design, as the drive shaft is not supporting the weight of a heavy fluid coupling. Another feature of the flexibility that the electronic variable speed drive controlled squirrel cage motor can offer is the capability of vertical mounting of the motor. Selecting this mode of mounting could lead to a reduction in capital cost of the total installation, due to possible variation in mechanical structural design. Not all of the fluid couplings can tolerate this mode of mounting.

As mentioned before, the utilisation of standard software features that are resident in the drive is a more economical solution than implementing the same function in external control equipment.

Running costs of the electronic variable speed drive are noticeably lower than the fluid coupling solution as the efficiency of the electronic variable speed drive is better than 98% and the power factor of the current drawn from the supply is better than 0,93 throughout the speed range for voltage source inverters.

When considering only the capital cost of the fluid coupling solution that provides a performance that approaches the performance of an electronic variable speed drive the electronic solution is more often than not the more expensive solution, but when the total capital cost of the conveyor drive systems are compared, the electronic solution is invariably the more economic solution. When running costs of the two solutions are compared the electronic solutions are the more economical solution.

One disadvantage of the electronic variable speed drives is the possibility that the injection of harmonic currents might adversely influence the operation of other equipment. When this problem is likely to occur, the remedy is to use a 12 pulse incoming unit to eliminate the offending 5^{th} and 7^{th} harmonics. The transformers feeding the electronic variable speed drives are also influenced by harmonic currents. If however the flux densities and the core bracing used by the transformer manufacture are on the conservative side no ill effects should be experienced. The transformer will also not be subjected to the 6-7 times starting current that is inherent in the D.O.L. starting method.

The cables used in electronic variable speed drive solutions are special in the way that only symmetrical three core cables and a separate external earth wire should be used. The ECC type of cable, which is commonly available especially in Natal, has a number of the steel armouring wires substituted with those made of copper. The use of this type of cable provides suitable screening to ensure reliable operation of other equipment in the vicinity of the electronic variable speed drive and motor. The cost of this cable is not significantly higher than the non ECC equivalent. The cables should be selected to allow for the harmonic currents.

Environmental Issues

The operating environment that the electronic variable speed drive should be subjected to is no more arduous than that required for any switchgear for all types of conveyor control. For maximum reliability the ambient temperature should be controlled to a maximum of 40°C, the relative humidity should be controlled to less than 95% and be non-condensing and the chemical corrosion and solids contamination of the air should not exceed the levels of I EC 721-3-3 3C2 and 3S2 respectively.

The electronic variable speed drives are manufactured according to IS014001 environmental standards. These drives do not emit any solids, liquids or gas when operating normally or under fault conditions. The same cannot be said about the fluid coupling with the emission of oil when ever a fusible plug blows and the messy clean up operation that must be undertaken.

The physical foot print of an electronic variable speed drive would not be significantly larger than the D.O.L. motor starting equipment and the extra load sharing automation equipment. If the D.O L. motor starting equipment is substituted with reduced voltage starting equipment then the physical sizes are very similar.

CONCLUSION

This paper has described the use of various motor starting and control techniques that have been used in conveyor applications. The benefits and disadvantages of the D.O.L started squirrel cage motor; the slipring motor and associated control gear; the squirrel cage motor with or without a reduced voltage starter and a fluid coupling and finally the electronic variable speed drive and squirrel cage motor have been discussed.

The conclusion that can be reached is that the electronic variable speed drive and squirrel cage motor should provide the most economic solution due to the superior controllability, its contribution to reduced maintenance, its inherent better reliability; and its contribution to reduced capital and running costs.

CV

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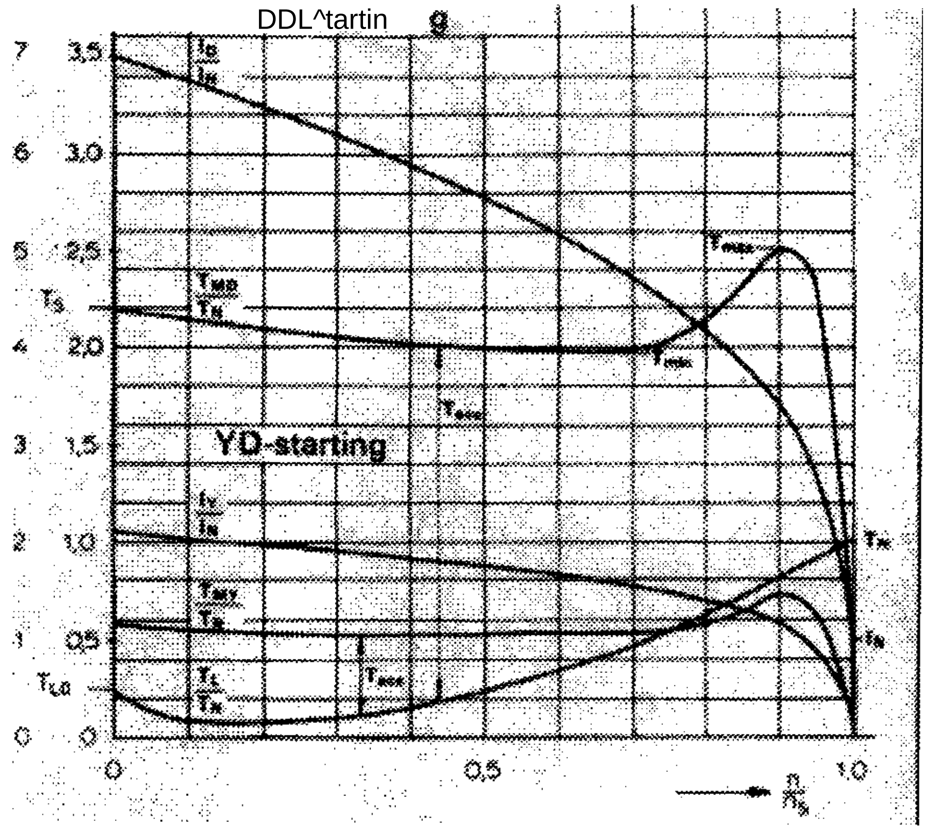

Figure 1 Typical motor current and torque curves