

FLUID COUPLINGS vs ELECTRONIC SOFT STARTS IN THE DRIVE TO CONVEYORS

Anthony G. Bolt
Fluidrive Engineering Company Limited

INTRODUCTION

Today our lives are becoming totally dependant on electronics. It's not surprising then that when people are faced with a problem involving electricity or control or when engineers are looking to improve systems, their first thoughts turn to electronics.

Whilst mechanical engineers know at least the basics of electronic drives, the vast majority of colleges and universities teach little or nothing about hydrokinetic drives or fluid couplings (not to be confused with hydrodynamic drives - hydraulic motors - which are totally different in operation and application). If mechanical engineers are not taught about fluid couplings, electrical engineers stand no chance and electronic engineers even less than that.

The first exposure most engineers get to fluid couplings is when they get into industry. It is therefore no surprise that all the advantages of fluid couplings are rarely understood, so it is easy to see why one can think that electronics can perform the same function.

The purpose of this paper is to explain the operation of fluid couplings and their electronic equivalent, the ramped voltage soft start and to show that fluid couplings do more than merely soft start and can offer several advantages over their electronic rivals.

2. SCOPE OF COMPARISON

The electronic soft start's design and price is such that it's nearest fluid coupling equivalent is the "Traction Type" fluid coupling with or without delay chambers, nozzles etc.

Both the traction type fluid coupling and the electronic soft start are ideally suited to the small to medium size of drive (i.e. 50 to 300/400 kW) where motors are switched on and off to start and stop the conveyor and where acceleration is completed in about 45 seconds or less. It is this sector of the market that this paper concentrates on.

It is clear that scoop type fluid couplings are used on conveyors with many hundreds and even thousands of kilowatts installed power, are used for long acceleration times with very fine torque control or where it is not desirable to keep stopping and starting the motors but these drives are not considered in this paper.

3. HOW THEY WORK

3.1 FLUID COUPLING

The fluid coupling is a hydrokinetic drive which means that power is transmitted by kinetic energy. The input of the fluid coupling is connected to a prime mover, usually a caged induction motor, and the output to the driven machine either directly or through a gearbox.

The circuit, which is the heart of the fluid coupling, comprises of an impeller (the input side) and a runner (the output side) - see Fig.1. The impeller acts as a centrifugal pump and the runner as a turbine.

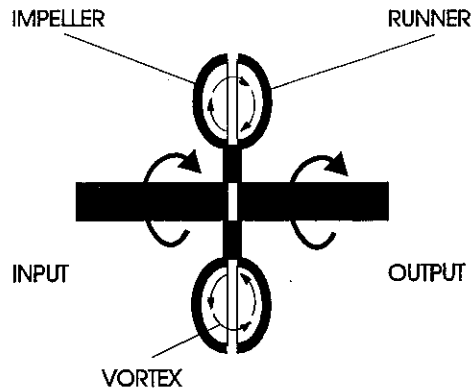


Fig.1 - Principles of Operation

When the motor starts it only feels the input side of the fluid coupling as there is no connection between the input and output of the fluid coupling. As the motor comes up to speed oil is picked up by the vanes of the impeller and, due to the circuit shape, thrown across to impinge on the runner. The oil flowing in the runner is returned to the impeller.

The oil path forms a vortex which can be likened to a coil spring bent so that it's two ends are joined; the more oil in the vortex the stronger the drive, the less oil the weaker the drive. The oil is given kinetic energy by the input and it gives up this energy to the output. As efficiency of energy transfer is virtually 100%, all the energy given to the output is either converted into work driving the conveyor or heat due to slip in the fluid coupling.

The torque build-up on the output shaft is proportional to the square of the input speed and the quantity of oil in the circuit vortex. The more advanced type of fluid coupling available today is fitted with chambers and nozzles to control the quantity of oil in the vortex during acceleration and to achieve a low slip when operating at full speed. These types of fluid coupling are generally known as super soft start couplings.

3.2 ELECTRONIC SOFT START

The principle of the electronic soft start is to ramp the motor voltage up from zero to full volts in a controlled fashion and over a set time period.

It is perhaps a good time to be reminded that the torque a motor produces is proportional to the square of the applied voltage.

The voltage is varied by allowing only part of the sine wave to pass to the motor. This is achieved using solid state power switches to turn on and off at pre-determined points in each cycle of the mains supply frequency. So in the case of a 50 Hz supply the solid state switches will turn on and off fifty times per second (60 times in the case of a 60 Hz supply). The type of power switch used is called a thyristor.

A thyristor is like a diode, it can pass electricity in a forward direction but blocks it in a reverse direction. The difference between a diode and a thyristor is that the thyristor has a "Gate" which will also block current flow in the forward direction until it's gate is signalled to open or, to use more technical jargon, the thyristor is "fired". Once turned on, the gate signal is removed and the thyristor remains on until the current through it drops to zero which conveniently happens during each cycle of the mains supply.

If two thyristors are wired in parallel and in opposite directions - see Fig.2 - then with correctly controlled firing all, or part of the A.C. wave can be passed to the motor. One thyristor will pass the positive part of the cycle and the other will pass the negative.

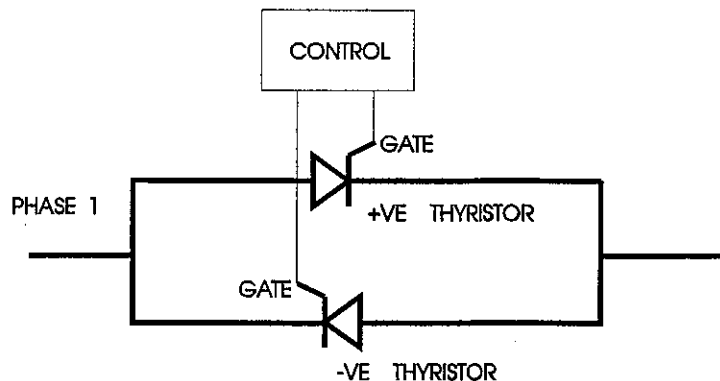


Fig.2 - One Phase of a Three phase Electronic Soft Start

Fig.3 shows one cycle of one phase of the mains wave divided into 360 degrees; the positive half 0 to 180 and the negative half 180 to 360. In theory, if we fire the positive thyristor at say 175° it will turn on and pass current until 180° is reached and then turn itself off; we also turn the negative on at 355° and it turns off at 360°. By progressively firing the thyristors earlier in the cycle more and more of the sine wave is passed to the motor until we end up firing the positive thyristor at 0° and the negative at 180° at which time the full A.C. wave is fed to the motor. Hence a variable voltage is achieved by changing the firing angle of the thyristors.

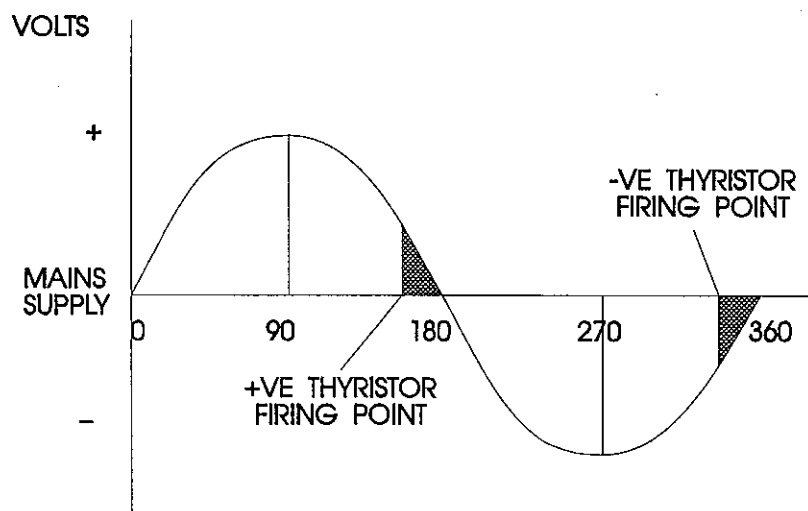


Fig.3 - Mains Cycle Including Thyristor Firing Points

A simple soft start, and the cheapest, will merely ramp the voltage from zero to full volts over an adjustable time period whilst the more expensive complex ones offer different time ramps, current limiting trips and time/speed ramps.

A simple uncontrolled soft start will merely ramp up the voltage to the motor over a period of time. The time period will be a compromise - too long and the motor will heat up too much; too short and you lose the advantage of the soft starter.

Once up to full voltage you are at the mercy of the motor torque speed curve. Whilst this may be tolerable on small conveyors, it will not be acceptable on the size of conveyors we are discussing.

It will become clear therefore that if we want to approach the performance of a fluid coupling, the more expensive controllable soft start is essential.

4. THE CAGED INDUCTION MOTOR

The caged induction motor or squirrel caged motor is cheap, robust, efficient and reliable so is by far the most common electric motor for most industrial and mining applications.

It is not the intention of this paper to explain how this type of motor works but it is important to understand the torque characteristics and relationship between torque, current and voltage. Basically both torque and current are proportional to the square of the voltage, e.g. at 90% volts both torque and current are 81%.

The torque characteristics of caged induction motors vary considerably depending on power, type, age of design and condition of windings:-

- Power - As a rule a low power motor is less efficient than a high power motor.
- Type - Different types of motors are available e.g. standard, high torque, high efficiency - each has different characteristics.
- Age - Like most things motors have improved over the years so older motors tend to have different characteristics to newer designs.
- Condition - A re-wound motor will have different characteristics to the original.

Fig.4 shows the characteristics of two common motors. Note the torque curve for each particularly the start torque (known as the locked rotor torque), the minimum torque and the maximum torque (known as the pull out point).

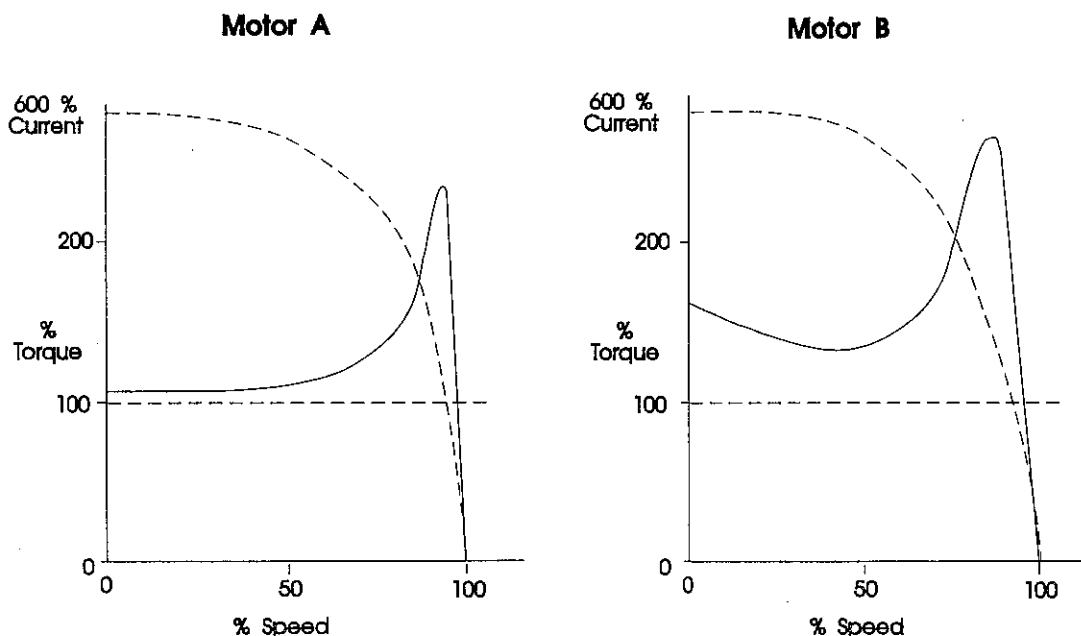


Fig.4 - Characteristics of Two Standard Motors

5.0 SOME CONVEYOR DRIVE REQUIREMENTS

Typically a conveyor will be designed with its full load demand being about 90% of the motor full load power. The power must be applied smoothly and progressively whilst the conveyor accelerates to full speed.

A conveyor is a constant torque machine so fully loaded it will demand 90% of the motor full load torque regardless of its speed. It also needs torque over and above this to accelerate the conveyor from rest to full speed. This torque is known as the acceleration torque.

The maximum acceleration torque that a conveyor can accept is selected by the conveyor designer and many factors are taken into consideration to decide this. A small, straight, level or inclined conveyor may be able to accept an acceleration torque of 180 to 200% of full load torque whilst a longer high speed conveyor with a vertical curve and multi-motor drive will require the acceleration torque not to exceed 140%.

Ideally the acceleration must start gradually, increase to the maximum allowed, stay constant for until near to full speed and then gradually decrease until full speed is reached.

The motor(s) must be capable of not only running the conveyor but also accelerating it to full speed. This means the motor(s) will produce in excess of full load torque for the acceleration period. Care must be taken to ensure the motor(s) are not overheated during the acceleration phase and can also handle the number of starts per hour the customer requires without overheating.

No shocks must be allowed to be passed to the conveyor causing oscillations to be set up in the belt and, ideally, any oscillations that may be set up in the belt (e.g. by sudden loading) should be absorbed by the drive.

If multi-motor drives are used the power demands should be balanced leaving no motor to take an uneven share of the load.

6.0 STARTING THE DRIVE

For this example we will assume the full load demand of the conveyor is 90% of motor full load power and acceleration torque must not be more than 140% of full load motor torque and the conveyor must be able to start under the fully loaded condition.

So, what type of starting system to use to start the motor/conveyor - direct on line, electronic soft start or fluid coupling?

6.1 THE DIRECT ON-LINE (D.O.L.) START

For the conveyor drives in the power range we are discussing a D.O.L. start is out of the question. Regardless of what type of motor is chosen (see Fig.4), the sudden application of torque when the motor is switched on, the high peak torque at the motor pull out point, the high current draw during acceleration and the lack of motor protection means that D.O.L. starting is usually considered unacceptable.

6.2 FLUID COUPLING WITH D.O.L. MOTOR

Taking the motors shown in Fig.4 and superimposing the fluid coupling characteristic we get the results shown in Fig.5.

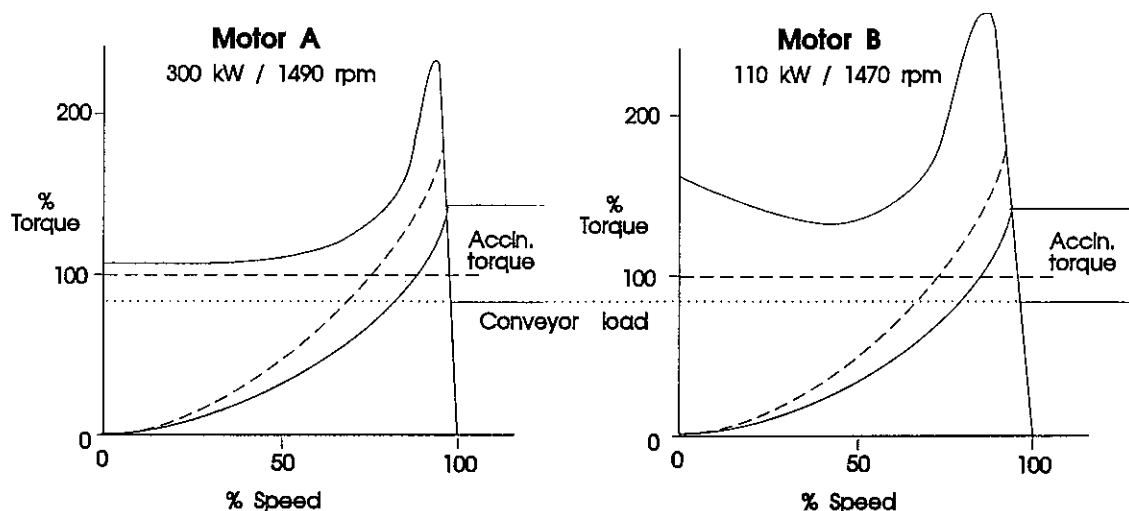


Fig.5 - Fluid Coupling with D.O.L. Motor

The torque between the motor and fluid coupling curve is the torque available to accelerate the motor and the input side of the fluid coupling and hence the motor comes up to near full speed in just 2 or 3 seconds.

The torque under the fluid coupling curve is the torque being passed to the conveyor and torque between the conveyor demand line and the fluid coupling torque is that available to accelerate the conveyor.

With the motor passed it's pull-out point it is working on the most efficient part of it's torque/speed curve and therefore current draw during the acceleration of the conveyor is kept low.

The acceleration torque is selected by changing the oil filling in the fluid coupling and in some cases chambers and nozzles may be fitted to give the results required by the designer. Provided an experienced manufacturer of fluid couplings is selected an acceleration torque of anything between 140% to 250% of motor full load torque may be selected.

The most advanced types of traction type fluid couplings are capable of having an initial starting torque down to 60% of full torque, building up to the normal accelerating level over a time period selected by nozzle sizing.

6.3 THE RAMPED VOLTAGE ELECTRONIC SOFT START

Taking the motors shown in Fig.4 and applying a variable voltage to them we get the results shown in Fig.6. The maximum torque that can be developed by the motor at start-up is it's locked rotor torque.

Taking motor "A" we need to ramp the voltage up to about 90% to achieve conveyor breakaway, current at this point will be about 485% of full load current. The voltage must now be ramped up to 100%, current will be 600% and even then the maximum torque you can achieve is only 110%. So the motor must struggle until about 75% speed when the torque rises rapidly to 300% before dropping down to the normal running level.

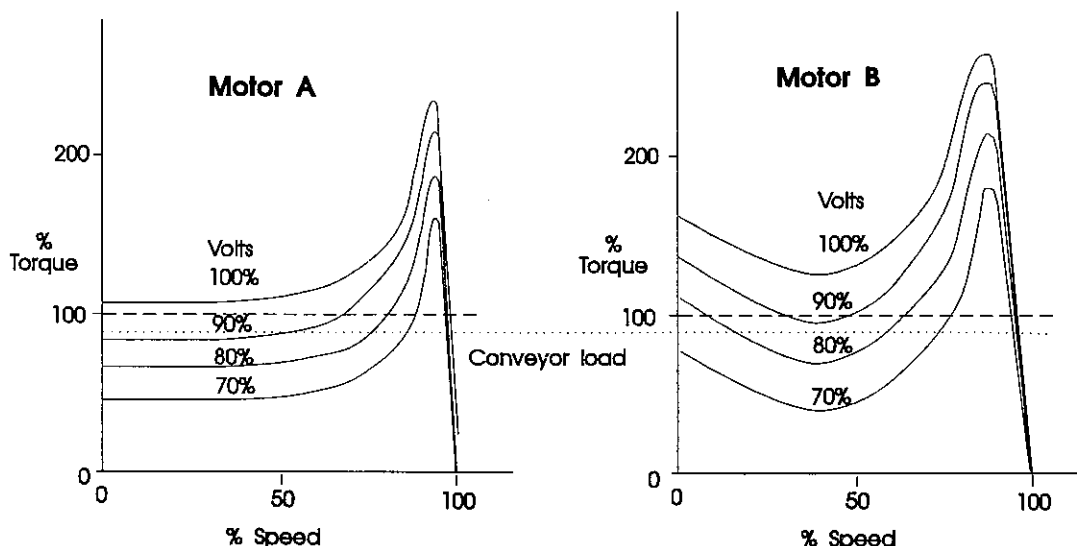


Fig.6 - Ramped Voltage Soft Start Effect on Motor

Taking motor "B" we need to ramp the voltage up to about 80% to achieve conveyor breakaway, current at this point will be about 385% of full load current. To achieve the required full accelerating torque the voltage will need to be ramped to 100%, the corresponding current will be about 600% of full load. Once the motor torque starts to rise the current begins to fall. Without control and the voltage now at maximum the motor torque will rise to about 250% and then drop to normal running torque.

In both cases the torque that is accelerating the conveyor is the difference between motor torque and demand torque, it is also assumes that **FULL MAINS VOLTAGE IS AVAILABLE DURING THE START-UP.**

A simple soft start is very limited in operation and it's starting ramp time will be a compromise; too short and the full motor curve will be reached too soon; too long and the motor will overheat.

However there are a number of precautions that one can take to stand the best chance of using a soft start to get an acceptable performance from it:-

- a) Introduce control into the soft starter. Common extra's available with today's latest range of soft starters are:-

Kick Start - a high voltage for 1 or 2 seconds, originally introduced to help overcome stiction.

Current Limit - an adjustable maximum current level that the starter will not allow the drive to exceed but with this feature we must again compromise; set too high and there will be too much torque at the high speed end of the motor curve; set too low and drive will not produce enough starting torque.

More complex extras are available but put the cost up considerably and, because of their complexity and market size, few manufacturers offer them, e.g. Tacho feedback adds 40 to 50% to the price.

- b) Oversize the motor so that there is no chance of the locked rotor torque being a limiting factor (we must be careful that the drive can now take the torque of the larger motor).

7.0 ADVANTAGES OF FLUID COUPLINGS

Whilst both systems will apply the initial starting torque smoothly there are a number of other advantages when using a fluid coupling to start/drive a conveyor:-

- a) Can Use Smaller Motors and Transformers
- b) Can Be Fitted to Any Motor
- c) Tolerant to Poor or Low Electrical Supply
- d) Stall Protection
- e) Absorbs Shocks
- f) No Problems with Environment
- g) Lower Starting Current
- h) Load Sharing
- i) Starts Overloaded Conveyor
- j) Stable Technology
- k) Simple Mechanical Device
- l) Eliminates Shaft Coupling

a) Can Use Smaller Motors and Transformers

We are no longer limited to the locked rotor torque of the motor so the fluid coupling can make maximum use from the minimum motor size. If necessary the demand power can equal the motor power and the drive will still operate perfectly well.

With an electronic soft start it is essential to ensure that the limited locked rotor torque is safely in excess of what is required. It is therefore usual to oversize the motor (particularly in the case of motor B)

Of course, smaller motors mean smaller transformers - another cost saving.

b) Can Be Fitted to Any Motor

The motor characteristic is not important to the fluid coupling it will work equally well with motor type A or B or almost any other characteristic as the motor is only allowed to see the load after it has accelerated passed it's pull out point.

With electronics the motor characteristics must be taken into account. If the drive has been selected to work with motor type A then it is unlikely to work with motor type B.

This point is important not only at the design stage but also if a motor is replaced on a drive. With electronics you must play safe and replace with an identical motor whereas the fluid coupling can be matched to any motor.

c) Tolerant to Poor Electrical Supply

Electrical supply to the motor can vary for many reasons e.g. how close the motor is to the transformer, basic mains fluctuations, by being at the end of a long electrical supply line. It is not unusual for specifications to be written stating that a 20% voltage drop must be taken into account. A fluid coupling can be selected to get around this problem. The only solution with electronics is to oversize again.

Harmonics on the mains and spikes due to lightning can also cause problems with electronics but have no effect at all when using fluid couplings.

d) Stall Protection

If the load on the motor increases suddenly due to a conveyor jam or stall the fluid coupling will simply slip to protect both the conveyor and the drive. In many instances it is the motor rotor inertia that causes the most damage. Fig.7 shows the effect of the motor rotor inertia at the gearbox output. With a fluid coupling the motor rotor is isolated from the rest of the drive by the fluid coupling.

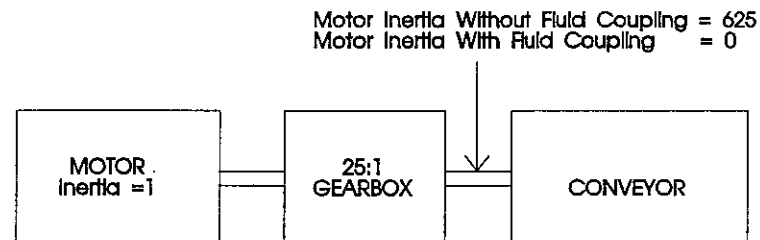


Fig.7 - Inertia Effect of Motor

Electronics can switch the motor off in the event of stall but cannot isolate the motor rotor inertia.

e) Absorbs Shocks

The fluid coupling provides a cushion between motor and conveyor and between conveyor and motor. Any shocks in the system whether generated by the motor (harmonics, spikes or fluctuations in supply) or the conveyor (jamming or sudden heavy loading on short conveyors) will be absorbed by the fluid coupling. Electronics cannot act as a cushion.

f) No Problems with Environment

The fluid coupling will work equally well in hostile environments such as extreme cold, extreme heat, humid, dusty, dirty, caustic and acidic conditions. Electronics are a lot more particular on what environment they operate in so a little more care must be taken when siting the soft start unit.

Being non-electrical and hence intrinsically safe, the fluid coupling is ideal for use in hazardous areas where ignition of dust or gas may be a problem.

g) Lower Starting Current

Because the fluid coupling utilises the most efficient part of the motor torque/speed curve, once the motor has accelerated itself up to speed the current drawn is approximately proportional to acceleration torque (i.e. 140% acceleration torque = 140% full load current).

The electronic soft start will draw high current (400 to 600%) until the motor reaches it's pull-up point (i.e. for about 75% of the acceleration time).

h) Load Sharing

When two or more motors are being used to drive a conveyor there will be differences between each drive. Some of the difference will be due to manufacturing tolerance in the motors and some will be due to the speed difference between the drive drums on the conveyor.

If two motors rated at 1480 rpm are purchased one may develop it's rated power at 1485 rpm whilst the other may develop it's at 1475 rpm. This will create an imbalance between the two drives and, if left uncorrected, the more efficient motor will take more of the load - see Fig.8.

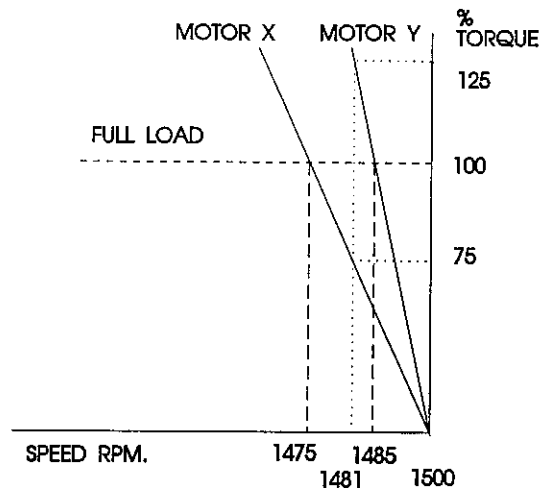


Fig.8 - Balancing of Two 1480 RPM Motors

Also, if two drives are operating on separate conveyor drive pulleys another imbalance will be created due to the difference in speed between the primary and secondary pulleys caused by the difference in tensions (see Fig.9). The speed difference will be dependent upon the belt type and load. For steel cord belt the difference will be between $\frac{1}{4}$ and 1% and for fabric belts $\frac{1}{2}$ and $1\frac{1}{2}$ %

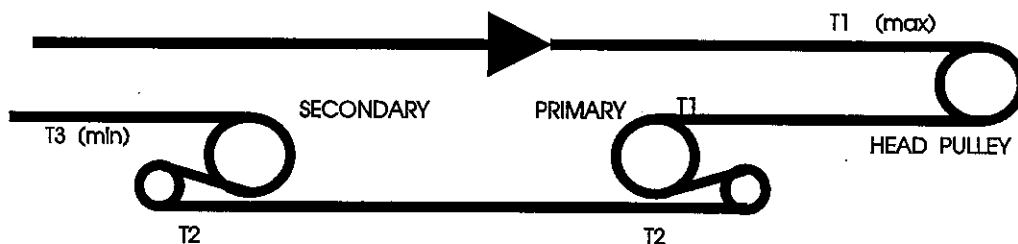


Fig.9 - Tensions Through a Dual Drive

If the out of balance is ignored then one drive will draw more power than the other. This will not only cause uneven wear between the drive modules but will also upset the tension distribution between primary and secondary.

The fluid coupling can make up these differences and balance the loads on the motors simply by changing the quantity of oil in the coupling.

The electronic soft start does not have a load balancing facility and even if it did it can only reduce the voltage thereby inducing slip into the motor. This causes a higher current draw and can easily lead to overheating of the motor.

i) Starts Overloaded Conveyor

In the case where a conveyor has been stopped in an overloaded condition the fluid coupling will stand a much better chance of re-starting it, even if a small temporary increase in oil fill is required.

With a soft start, if starting torque is higher than locked rotor torque the drive cannot be started - so it's back to men and shovels.

j) **Stable Technology**

Fluid coupling technology is stable and as such spares and replacement units will be available for many years to come. Fluid couplings that are well in excess of 30 years old are still in service today and spare parts are still available for them.

Electronic technology changes rapidly with the consequence that if a soft start is purchased today it is likely to be obsolete in 5 or maximum 10 years.

k) **Simple Mechanical Device**

A fluid coupling is a simple mechanical device and can easily be understood by a mechanical fitter. Service or repair of fluid couplings that are in excess of 30 years old can easily be undertaken by the customer and spares are still available from fluid coupling manufacturers and agents.

If there is a problem with an electronic soft start most customers will stand little chance of trouble shooting and a replacement unit is the most sensible option.

l) **Eliminates Shaft Coupling**

The fluid coupling acts as a shaft coupling so no proprietary shaft coupling need be purchased.

8.0 OTHER CONSIDERATIONS

Obviously the electronic soft start must have some attraction in order for people to consider it. Some reasons for consideration are:-

a) **Less Rotating Equipment**

This is often used as a reason to remove the fluid coupling but whilst the fluid coupling is removed it is replaced by an extra piece of electronic equipment.

b) **Eliminates Motor Starter**

The soft start can be left in circuit during continuous running but the losses when using it continuously must be considered both from the heating point of view and long term energy losses. It is sometimes better to use a contactor and bridge out the soft starter, this will eliminate any losses in the unit and minimise any likelihood of damage to the unit caused by mains-borne spikes.

c) **Efficiency**

Whilst the efficiency of the soft starter is better than a fluid coupling it is more usual to use a less efficient motor to get the higher starting torque that is not available from a high efficiency motor.

The soft start is usually available with an energy saving feature. This reduces the voltage to the motor when the motor is lightly loaded. Obviously if it has been decided to use a motor contactor to bridge out the soft start then this feature cannot be used.

d) **Soft Stop**

The electronic soft start can also ramp the voltage down to stop the drive. However, when it is essential to soft stop a conveyor it is usual to incorporate a flywheel so that in any event, particularly power failure, the conveyor will get an extended stop.

9. EXAMPLE

Central Canada Potash have been using fluid couplings and electronic soft starts for more than 10 years now. Originally the idea was to replace all fluid couplings. This never happened and they are using several generations of soft starters and fluid couplings. Now after several years of experience with both systems they are moving back to fluid couplings.

The decision to move back came after making a study of two identical conveyors that run alongside each other, conveyors 528 and 533. The conveyors are advancing as the mine is extended so the load on them increases as they are extended.

Conveyor 528 - driven by 2 x 250 HP / 1787 rpm Westinghouse 509U motors and Startco SE-901 PM electronic soft starters.
Transformer = 1000KVA - 13.8 KV / 600V.

Conveyor 533 - driven by 2 x 200 HP / 1780 rpm Toshiba 447TZ motors direct on line started with Fluidrive 480 CDRS super soft start fluid couplings.
Transformer = 500KVA - 13.8KV / 600V.

As the conveyor was extended a record was kept of any faults or problems that occurred during operation. The following are excerpts from the records:-

- 170m long - start length of conveyors.
- 800m long - 528 started blowing breakers and main fuses and also failed to start a loaded conveyor. Conveyor was kept running whenever possible.
- 920m long - 528 getting worse. Often need to shovel off material to get conveyor started.
- 1940m long - 528 will no longer start even an empty belt.
- 2800m long - conveyor 533 still operating without any problems.

So with 100 HP less power and a transformer half the size conveyor 533 was able to operate at a length at least 44% longer than conveyor 528.

Standard policy of the mine now is to use fluid couplings, over-ride the soft start but use the programmable part of the package for power saving by monitoring drive power, dropping out motors that are not required and pulling motors as they become necessary.

10. CONCLUSIONS

Fluid couplings still play a major part in the power transmission market today particularly on conveyors of all types, shapes and sizes. Their advantages are not always appreciated particularly by the newer engineers brought up in an electronic world. Electronics seem to be the panacea to today's engineer and they have a reliable, clean and efficient image. But they cannot change the fundamental laws of physics (not yet anyway).

As can be seen from section 7, the fluid coupling has a great deal to offer and if what little maintenance that is required is carried out the fluid coupling will continue to give these benefits for the life of the conveyor and longer.

Section 9 is an example of the application of just some of the benefits that the fluid coupling has to offer. The maintenance engineer involved has been so pleased with the performance of the fluid couplings that he is not only incorporating fluid couplings in all his drives but he has also written to all the other mines in the group to advise them of his success.

So before you disregarded the fluid couplings as being "Old Technology" look more closely at what they can offer and you will find that there are still many reasons for using them today and for many years to come.

AUTHOR

Anthony Bolt has spent all of his working life in heavy engineering and power transmission. Starting with a 5 year apprenticeship with London Underground he continued working for them in plant and rolling stock maintenance. Following on from London Underground he spent 5 years with Wichita as an Applications Engineer selecting clutches and brakes for high power applications such as presses, shears and steel/paper converting equipment. The last 20 years he has spent with Fluidrive Engineering starting as an Applications Engineer and moving through sales to his position now as International Sales Manager.

During his time at Fluidrive he has been heavily involved with the application of all different types of fluid couplings fitted to conveyors. The work has not only involved technical selection but also the development of controls for high powered conveyors.

His experience in electronics has been gained by several practical and theoretical courses on the subject. This knowledge has been useful in the design of control systems and evaluating the electronics as a competitive technology.