Open loop control method for conveyor belt transmission engineering essay

Before the advent of modern automation techniques, factory workers often had to travel from project to project. The cumulative effect of all this physical motion was additional stress and inefficient use of the worker’s time. The development of conveyor belts allowed the project to come to the worker, instead of the worker to the project. Parts could then be transported by other conveyor belts to additional workers, and eventually to the shipping docks for delivery.

Many conveyor belts work on the principle of variable speed control. If a particular belt moves too slowly, workers may find themselves waiting for parts. If a conveyor belt moves too quickly, parts may be damaged or workers may become overwhelmed. Much of a factory supervisor’s time is spent adjusting conveyor belts for maximum efficiency. This is especially important in food production factories, where conveyor belt speed and proper cooking time work hand in hand.

Project objectives

Modeling of a open-loop control method for conveyor belt transmission

Modeling of a close-loop speed control method for conveyor belt transmission

Research on the performance comparison for variable mass material input

1. 2 Organization of thesis

Chapter 2: This chapter thoroughly introduce what conveyor transmission system is and provides a brief history about it. Six categories of typical conveyor transmission system have been introduced. It also explains the sources and types of breakdowns in conveyor belt, as well as the effect of those breakdowns cause in the transmission line. Then, this chapter also discusses about the importance to have speed control for the conveyor belt transmission system.

Chapter 3: This chapter mainly focus on different types of motors. It specifically explains about the AC asynchronous motor which is the most widely used in heavy industry. The different speed control methods of AC asynchronous motors have been compared in several aspects.

Chapter 4: In this chapter, PID controller is discussed in details for process control, including its definition, history, applications, tuning method and implementation. Unlike other kinds of papers concerning PID control approach, the weakness and bad behaviour were brought about as well so that an objective picture of PID method could be completed.

Chapter 5: At the outset, this chapter gives some key modeling process, and then provides the complete models for simulation both of open-loop control and close-loop speed control. With these models, simulation results can be get to make some comparisons. The close-loop results show the performance of different controller parameters on the transmission system with a variable mass material input on several discrete speed value, corresponding to the open-loop curves those seem not to be quite good.

Chapter 6: This chapter summarizes discussion and conclusion about the performance of speed control on the transmission system, and then gives out some recommendations and future works that can be done in speed control for conveyor belt transmission system.

2. 0 CONVEYOR BELT TRANSMISSION SYSTEM

Conveyor belts are generally endless loops which move parts or materials from one location to another. Conveyor belts are often driven by variable speed electric motors or by other moving parts in a complex system. They are commonly found in factories, grocery stores, warehouses and public transportation centers.

Further refinement of conveyor belts allowed factory managers to create automated or semi-automated production lines. Individual parts could be moved through automated machinery for routine processing, leaving workers free for quality control tasks or other higher responsibilities. Conveyor belts also proved useful for transporting heavy or hazardous products, reducing worker injuries.

The use of conveyor belts is not restricted to factories. Bakeries and pizza shops often use a slow-moving wire conveyor belt to move their products through an oven. Grocery stores use conveyor belts in their check-out lines to bring items to the clerk and bagger. Airports and other public transportation systems use conveyor belts to deliver checked baggage to customers. Warehouses use long conveyor belts to offload products from incoming trucks or to load outgoing ones. Escalators found in department stores could also be considered conveyor belts, as are ‘ people movers’ in larger airports.

2. 1 History

Primitive conveyor belts were used since the 19th century. In 1892, Thomas Robins began a series of inventions which led to the development of a conveyor belt used for carrying coal, ores and other products.[6] In 1901, Sandvik invented and started the production of steel conveyor belts. In 1905 Richard Sutcliffe invented the first conveyor belts for use in coal mines which revolutionized the mining industry. In 1913, Henry Ford introduced conveyor-belt assembly lines at Ford Motor Company's Highland Park, Michigan factory.[7] In 1972, the French society REI created in New Caledonia the then longest straight-belt conveyor in the world, at a length of 13. 8 km. Hyacynthe Marcel Bocchetti was the concept designer. In 1957, the B. F. Goodrich Company patented a conveyor belt that it went on to produce as the Turnover Conveyor Belt System. Incorporating a half-twist, it had the advantage over conventional belts of a longer life because it could expose all of its surface area to wear and tear. Möbius strip belts are no longer manufactured because untwisted modern belts can be made more durable by constructing them from several layers of different materials.[8]. In 1970, Intralox, a Louisiana based company, registered the first patent for all plastic, modular belting. In 1963-64, First Indian Small Scale Industrial Unit with Japanese Plant for Rubber Belts for Conveyor / Elevator / Transmission was installed near National Capital Territory of Delhi and its MrBelts Conveyor Belting has been widely used in Steel, Cement, Fertilizer, Thermal Power, Sponge Iron Plants and Coal/Mineral establishments, Port Trusts and similar material handling applications of Industry for the last over 4 decades

2. 2 Types of Conveyor System

2. 2. 1 Wheel Conveyor System

A wheel conveyor system's setup consists of skate wheels that are mounted on an axle placed in a row. Depending on the weight of the material being transported, adjustment of both the wheel spacing and the slope for load movement is provided. Being simpler in construction, the system is flexible, scalable and more economical with light-duty applications as compared to a roller conveyor system.

2. 2. 2 Roller Conveyor System

A roller conveyor system has two variants, but both utilize a minimum of three rollers that provide support to the smallest load all the time. Then there are tapered rollers that orient the load around a curved path. The gravity-type system is alternative to the wheel conveyor system that is used for heavy-duty applications. It utilizes a slope for load movement to facilitate the accumulation process. The powered variant utilizes a belt or chain drive for force-sensitive power transmission useful in merging and/or sorting applications.

2. 2. 3 Chain Conveyor System

A chain conveyor system has one or more endless chains that directly carry the load. These chains are placed in a parallel chain manner that can be used in transporting pallets. One variant is the vertical chain conveyor that is used for transferring loads continuously in a vertical direction at high speeds.

2. 2. 4 Slat Conveyor System

A slat conveyor system uses slats placed at discrete positions, and these slats are connected to a chain. Through drives that control orientation and positioning of the load, the transported unit is able to retain its position while being conveyed. The system is used in applications transporting heavy loads that might otherwise damage the belt as in bottling and canning plants.

2. 2. 5 Vibrating Conveyor System

In vibrating conveyor systems, the main component is an elongated load-carrying structure called a trough, bed or tube, based on the application it is used for. A vibrating mechanism produces small amplitude vibrations at a high frequency. This conveys the individual product units and bulk materials. Due to its unique operational manner, it can be used to transport almost all kinds of granular as well as free-flowing materials.

2. 2. 6 Pneumatic Conveyor System

A pneumatic conveyor system uses pipes or ducts known as transportation lines. These ducts carry material mixture along with an air stream. The load gets transported to various locations through pipe lines propelled by the high velocity air streams.

2. 3 Components and Breakdowns

The belt conveyor system (BCS) consists of (fig. 3):

- drive unit (electric motor, coupling multistage gearbox),

- pulleys (drive pulley and other),

- belts (textile or with steel cords) with their joints,

- idlers,

- other (belt cleaning systems, control system, etc.)

Fig 2. 3. 1 Belt conveyor transmission system components

In this section we will consider the type of faults that may appear in belt conveyor systems with reference to conveyor component s.

The drive unit consist of electric motor, damping coupling, two or three stage gear-box and coupling that connect output shaft with pulley (fig. 8). A crucial object in this subsystem is gearbox. According to Matuszewski [5] in a considered lignite open cast mine even 14% of gearboxes may be replaced each year due to unexpected failures. These failures are related to the geared wheel wear or damages (broken tooth) and bearings (mainly over limit backlash due to environmental impact, also typical failures like outer/inner race, rolling element).

The mining pulley consist of two bearings, shaft, shell and coating (special material in order to improve belt-pulley contact). The most frequent failures for pulleys are: bearings and shells. For gearboxes number of failures related to geared wheels is 50%. Other critical failure is the damage of input shafts (probably because of overloading) . It may be surprising that bearing faults are not so frequent in gearboxes.

The failure analysis of idlers and belts are a bit different issue [7, 8, 11]. Idlers are used for supporting belts with transported materials. In some sense, idlers are similar to pulleys and consist of bearings and shells. One may expect similar types of failures. The support system for belt consists of three idlers. Because of different load for each idler usually side idlers are more subjected to damage. It needs to be added that in CM context of idlers change of condition is not the only one. Worn bearings in idlers will significantly increase external load for drive units so power consumption will increase. Damaged idlers and pulleys may be the reason of damage for belts.

Depends on application, belts used in conveyor systems may be divided into two groups: textile belts and steel cords belts. In underground mines usually the textile belts are used. In lignite mines both types may be applied. Expected problems for belts are related to belt (tear, puncture, cut of belt and abrasion of bottom/top covers) and its joints (connected using glue, vulcanized or mechanical joint) [10, 11]. Because of dimension and weight of a belt it needs to be transported in rolls, pieces up to 100-400 m long, depends on a belt type. In order to replace damaged a gearbox or pulley heavy machinery is required. In some cases due to environmental impact (for example rain) it takes a few times longer time.

If one consider the impact of damaged idlers it is another story. The idlers are quite small in comparison to pulleys; however, number of idlers is huge. Damaged idlers may cause failure of belt (the cut of a belt) or even may start fire (belt slipping on damaged idler may increase temperature up to 400°C, 450°C is the limit for so called “ difficult-to-burn” belt) and as it was mentioned energy consumption is arising dramatically.

Any of mentioned failure generates cost of breakdown of machines working in series. It as to be mentioned that a conveyor system, that with random material to be transferred the smoothness and stability of the conveyor belt transmisssion system should be guaranteed to extend all the components lifetime.

2. 4 Significance of Research

The belt conveyor is one of key components for most of manufacturing systems. Intelligent control of the conveyor leads to the feasibility of a Flexible Manufacturing System (FMS). For most of the assembly lines in manufacturing systems, different processing works applied to products mainly come from workers who is sitting along the conveyor. The products are conveyed by the belt conveyor from one working area to the next. If the average number of products entering one working area is greater than the average number leaving that area, the manufacturing process stagnates. It means that conveying speed is too fast so that more products are conveyed to workers in that working area than the quantity they can handle. Therefore, the conveying speed of belt conveyor needs to be adaptively changed based on the stagnation condition at each working area. On the other hand, if the defective rate of products monitored at outlet of conveyor is too large even though no stagnation has occurred at each working area, the conveyor still needs to be adaptively slowed down so that workers have more time to give their processing works with more cares In the long run, maximum number of manufactured products conveyed to the outlet of conveyor is hoped to be achieved if the speed of belt conveyor can be intelligently controlled Since the conveyor is driven by a servo motor, adaptive control algorithm can be designed to control the motor speed based on stagnation conditions at working areas or the defective rate monitored at the conveyor outlet.

In addition, belt conveyor is one of main electromechanical systems in heavy industry, especially in the coal transport system, its safe operation plays an important role in the whole coal output systems. Safety is an important aspect in our life, and coal mine still is a high-risk industry in the world. As one of main components in the coal transport system, the safe operation of belt conveyor plays an important role in the whole coal output systems. As the belt conveyors get longer, quicker and bulkier, it is often occurred that the belt rupture, coal vibration, belt slip on the drive pulley, uncontrolled running of the belt conveyor, belt fire and other safety accidents, which bring huge economical losses and threat miner life. In order to insure the miner safety and the normal production, it is significant to carry on safety investigation of the belt conveyor. Higher productivity and reliability are common goals for conveyor systems in mining operations. Key objectives include optimized mass flows, reduced energy costs and a well-coordinated workflow between the conveying and transport processes. And the key to this problem is to make sure that the transmission system should be operating at a smooth and steady speed. In a word, the steady speed of the conveyor belt transmission system is vitally important.[wiki]

3. 0 MOTORS FOR CONVEYOR

3. 1 General Motors

An electric motor is an electromechanical device that converts electrical energy into mechanical energy. Electric motors are found in applications as diverse as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and disk drives. Electric motors may be classified by the source of electric power, by their internal construction, by their application, or by the type of motion they give.

3. 1 Conveyor Motor Types

For a conveyor transmission system, the drive unit develops with time. And the motors still using in this era come to the 4 main types: brushed DC motor; brushed DC motor; . The working mechanism of the 4 kinds are discussed as well as their merits and drawbacks.

3. 2. 1 Brushed DC motors

A brushed DC motor has a set of rotating windings wound on an armature mounted on a rotating shaft. The shaft also carries the commutatora long-lasting rotary electrical switch that periodically reverses the flow of current in the rotor windings as the shaft rotates. The magnets field produced by the armature interacts with a stationary magnetic field produced by either permanent magnets or another winding a field coil, as part of the motor frame. The force between the two magnetic fields tends to rotate the motor shaft.

Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. Sparks are created by the brushes making and breaking circuits through the rotor coils as the brushes cross the insulating gaps between commutator sections. Depending on the commutator design, this may include the brushes shorting together adjacent sections – and hence coil ends – momentarily while crossing the gaps. Furthermore, the inductance of the rotor coils causes the voltage across each to rise when its circuit is opened, increasing the sparking of the brushes. This sparking limits the maximum speed of the machine, as too-rapid sparking will overheat, erode, or even melt the commutator. The current density per unit area of the brushes, in combination with their resistivity, limits the output of the motor. The making and breaking of electric contact also generates electrical noise; sparking generates RFI. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance (on larger motors) or replacement (on small motors). The commutator assembly on a large motor is a costly element, requiring precision assembly of many parts. On small motors, the commutator is usually permanently integrated into the rotor, so replacing it usually requires replacing the whole rotor. Therefore, DC motor brush design entails a trade-off between output power, speed, and efficiency/wear.

3. 2. 2 brushed DC motor

In this motor, the mechanical " rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient or more whereas DC motors with brush are typically 75-80% efficient.

Brushless DC motors are commonly used where precise speed control is necessary. They have several advantages over conventional motors: they are very efficient, running much cooler than the other equivalent motors; without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator; brushless motors have no chance of sparking, unlike brushed motors, making them better suited to environments with volatile chemicals and fuels. Also, sparking generates ozone which can accumulate in poorly ventilated buildings risking harm to occupants' health.

Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. There are numerous applications using a Brush DC Motor that could instead utilize the Brushless DC Motor. However a few factors might prevent the changeover. The first factor is start-up cost. Although the Brushless DC Motor is lower-maintenance than the Brush DC Motor, initial cost is more expensive, due to its advantageous construction. Second is complexity. A controller is required in order to operate a Brushless DC Motor, and is usually more convoluted than most controllers. A Brushless DC Motor also requires additional system wiring, in order to power the electronic commutation circuitry.

3. 2. 3 asynchronous AC motor

An asynchronous AC motor is an induction motor where power is transferred to the rotor by electromagnetic induction, much like transformer action. . Polyphase induction motors are widely used in industry. The simple design of AC motor is simply a series of three windings in the exterior (stator) section with a simple rotating section (rotor). The changing field caused by the 50 or 60 Hertz AC line voltage causes the rotor to rotate around the axis of the ac motor. The AC motor has the advantage of being the lowest cost motor for applications which require more than about 1/2 hp (325 watts) of power. This is due to the simple design of ac motor. Meanwhile, the simple design of the AC motor results in extremely reliable, low maintenance operation. Unlike the DC motor, there are no brushes to replace for ac motors. If run in the appropriate environment for its enclosure, AC motor can expect to need new bearings after several years of operation. In fact if the application is well designed, an AC motor may not need new bearings for more than a decade.

Although the most common and simple industrial motor is the three phase AC induction motor, there are still disadvantages of ac motor.

Expensive speed control

The electronics required to handle an AC inverter drive are considerably more expensive than those required to handle a DC motor. However, if performance requirements can be met — meaning that the required speed range is over 1/3rd of base speed — AC inverters and AC motors are usually more cost-effective than DC motors and DC drives for applications larger than about 10 horsepower, because of cost savings in the AC motor.

Inability to operate at low speeds

Standard AC motors should not be operated at speeds less than about 1/3rd of base speed. This is due to thermal considerations. In fact a DC motor should be considered for these applications.

Poor positioning control

Positioning control is also expensive and crude. Even a vector drive is very crude when controlling a standard AC motor. Servo motors are more appropriate for these applications.

3. 2. 4 Synchronous Electric Motor

A synchronous electric motor is an AC motor distinguished by a rotor spinning with coils passing magnets at the same rate as the alternating current and resulting magnetic field which drives it. Another way of saying this is that it has zero slip under usual operating conditions. Contrast this with an induction motor, which must slip to produce torque.

These motors can be made to operate at leading power factor and thereby improve the pf of an industrial plant from one that is normally lagging to one that is close to unity. And the key feature of a synchronous AC motor is it operates at a constant speed, irrespective of load, from no-load to full load. As well, electromagnetic power varies linearly with the applied voltage. These motors can be constructed with wider air gapes than induction motors making them mechanically better. What's more, efficiency of operation is usually high, especially in the low speed and unity power factor ranges.

However, the disadvantages are also quite obvious. These motors cannot be used for variable speed jobs as there is no possibility of speed adjustment. And it requires external source for supplying dc excitation, cannot be started under load, the starting torque being zero, may fall out of synchronism and stop when over-loaded and so on. In addition, for some applications these motors are not desirable as for driving shafts in small work-shops having no power available for starting and in cases where frequent starting or strong starting torque is required.

3. 3 AC Motor for Conveyor

Through the comparisons above, transmission system with AC motors are simple to make and can be reliable. And for the low cost, AC motors are overwhelmingly preferred for fixed speed applications in our industrial applications and for commercial and domestic applications where AC line power can be easily attached. In fact over 90% of all motors are AC induction motors. AC induction motors are found in air conditioners, washers, dryers, industrial machinery, fans, blowers, vacuum cleaners, and many, many other applications.

Using an AC drive for conveyor control allows the speed to be adjusted to changing needs. A partly loaded conveyor with a higher speed than necessary wastes energy and causes unnecessary wear. In controlling conveyors, AC drives also improve process control by enabling the collection of measurement and supervision information. The soft start of the conveyor with AC drives reduces the stress on gearboxes when the conveyor is started.

This paper mainly deals with the AC asynchronous motors, because for industry like coal mine, the asynchronous ones are the mainstream with many successful applications. In the design of the induction motor, operational characteristics can be determined through a series of calculations. Performing these calculations can help the engineer provide a motor that is best suited to a particular application.

3. 3. 1 SYNCHRONOUS SPEED

The speed with which the stator magnetic field rotates, which will determine the speed of the rotor, is called the Synchronous Speed (SS). The SS is a function of the frequency

of the power source and the number of poles (pole pairs) in the motor. The relationship

to calculate the SS of an induction motor is:

Where:

SS = Synchronous Speed (RPM)

f = frequency (cycles / second) = 60

P = number of poles (pole pairs)

3. 3. 2 MOTOR SLIP

The rotor in an induction motor can not turn at the synchronous speed. In order to induce an EMF in the rotor, the rotor must move slower than the SS. If the rotor were to somehow turn at SS, the EMF could not be induced in the rotor and therefore the rotor would stop. However, if the rotor stopped or even if it slowed significantly, an EMF would once again be induced in the rotor bars and it would begin rotating at a speed less than the SS.

The relationship between the rotor speed and the SS is called the Slip. Typically, the Slip is expressed as a percentage of the SS. The equation for the motor Slip is:

Where:

%S = Percent Slip

SS = Synchronous Speed (RPM)

RS = Rotor Speed (RPM)

3. 3. 3 EQUIVALENT CIRCUIT

To analyze the operating and performance characteristics of an induction motor, an

Equivalent Circuit can be drawn. We will consider a 3-phase, Y connected machine, the

Equivalent Circuit for the stator is as shown below:

Fig 3. 3. 1 Equivalent Circuit

Where:

V1 = Stator Terminal Voltage

I1 = Stator Current

R1 = Stator Effective Resistance

X1 = Stator Leakage Reactance

Z1 = Stator Impedance (R1 + jX1)

IX = Exciting Current (this is comprised of the core loss component = Ig, and a magnetizing current = Ib)

E2 = Counter EMF (generated by the air gap flux)

3. 4 Speed Control of AC Asynchronous Motor

With respect to the use of AC asynchronous motor, when used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. So the speed control of an AC asynchronous motor in the industry world is quite important.

From Equ. 1 we can get the speed torque characteristic of the machine as Fig. 3. 3. 2. The curve is rather steep and goes from zero torque at synchronous speed to the stall torque at a value of %S. Normally Slip may be such that stall torque is about three times that of the rated operating torque of the machine, and hence may be about 0. 3 or less. This means that in the entire loading range of the machine, the speed change is quite small. The machine speed is quite stiff with respect to load changes. The entire speed variation is only in the range SS to (1âˆ’%S)SS, SS being dependent on supply frequency and number of poles.

Fig 3. 3. 2 Relationship between torque and speed of induction motor

The coming discussion shows that the several speed control methods for induction machine, when operating from mains is essentially a constant speed machine. Many industrial drives, typically for conveyor in a belt transmission system, have typically constant speed requirements and hence the induction machine is ideally suited for these. However, the induction machine, especially the squirrel cage type, is quite rugged and has a simple construction. Therefore it is good candidate for variable speed applications if it can be achieved.

3. 4. 1 Applied voltage control

One may note that if the applied voltage is reduced, the voltage across the magnetizing branch also comes down. This in turn means that the magnetizing current and hence flux level are reduced. Reduction in the flux level in the machine impairs torque production. If, however, the machine is running under lightly loaded conditions, then operating under rated flux levels is not required. Under such conditions, reduction in magnetizing current improves the power factor of operation. Some amount of energy saving may also be achieved. Voltage control may be achieved by adding series resistors (a lossy, inefficient proposition), or a series inductor/autotransformer (a bulky solution) ora more modern solution using semiconductor devices. A typical solid state circuit used for this purpose is the AC voltage controller or AC chopper. Another use of voltage control is in the so-called ‘ soft-start’ of the machine.

3. 4. 2 Rotor resistance control

Clearly, the rotator speed is dependent on the rotor resistance. Further, the maximum value is independent of the rotor resistance. The slip at maximum torque is dependent on the rotor resistance. Therefore, we may expect that if the rotor resistance is changed, the maximum torque point shifts to higher slip values, while retaining a constant torque.

Note that while the maximum torque and synchronous speed remain constant, the slip at which maximum torque occurs increases with increase in rotor resistance, and so does the starting torque. whether the load is of constant torque type or fan-type, it is evident that the speed control range is more with this method. Further, rotor resistance control could also be used as a means of generating high starting torque. For all its advantages, the scheme has two serious drawbacks. Firstly, in order to vary the rotor resistance, it is necessary to connect external variable resistors (winding resistance itself cannot be changed). This, therefore necessitates a slip-ring machine, since only in that case rotor terminals are available outside. For cage rotor machines, there are no rotor terminals. Secondly, the method is not very efficient since the additional resistance and operation at high slips entails dissipation. The resistors connected to the slip-ring brushes should have good power dissipation capability.

3. 4. 3 Cascade control

The power drawn from the rotor terminals could be spent more usefully. Apart from using the heat generated in meaning full ways, the slip ring output could be connected to another induction machine. The stator of the second machine would carry slip frequency currents of the first machine which would generate some useful mechanical power. A still better option would be to mechanically couple the shafts of the two machines together. This sort of a connection is called cascade connection and it gives some measure of speed control as shown below. Let the frequency of supply given to the first machine be f1, its number poles b