PIPE CONVEYOR AND BELT: BELT CONSTRUCTION, LOW ROLLING RESISTANCE AND DYNAMIC ANALYSIS

Yijun Zhang, Conveyor Dynamics Inc., Bellingham, Washington, US

Robin Steven, Goodyear Engineered Products, Veyance Technologies, Inc., Marysville, Ohio,US

Abstract

New developments in the pipe conveyor and belt are advanced to address the growth in the capacity, length and complexity of pipe conveyor systems. Improved belt construction can offer better stability during horizontal curves and resistance to twist. Low rolling resistance rubber compound can significantly lower the power consumption and belt tension, producing capital and operation cost savings. Dynamic analysis, when used to analyze the conveyor's starting and stopping behavior, can improve the design and reliability of long overland pipe conveyor systems. For these three aspects, technical backgrounds and field installations as examples are discussed in this paper.

Introduction

Belt conveyors，as an efficient way of transporting bulk materials, have been widely applied in the mining, power generation, cement, ship port and industrial plants for several decades. The main benefit of belt conveyors compared to other material handling machines like trucks, trains and barges is the higher efficiency in the mechanical system, energy consumption and total cost over the long term, especially when conveyor system is design optimized (1). Trough belt conveyor is the ubiquitous type of belt conveyor. There are other belt conveys serving more specialized purposes, like pipe conveyors or tubular conveyors, high incline or high angle conveyors, wheel-on-rope type of conveyors like cable conveyors and Ropecon. When pipe conveyor was first started in 1980s in Japan (2), the principle benefits of using pipe conveyor was its ability to negotiate sharp curves and seal the transporting material. Rolling the belt into the pipe shape separates the material from the environment. It also reduces the area moment of inertia, which facilitates the bending of the pipe belt over horizontal and vertical curves. Over the last fifteen years, pipe conveyor saw not only increased number of installations and growth in the size and complexity of the system, but also better recognition by the general material handling sector as a feasible material handling system. India and China now represent the biggest market for pipe conveyors. In south east Asia , Australia and South America, a few major pipe conveyor installations are either operating, being erected or under planning. If these initial high profile systems are perceived to be successful, it is reasonable to expect that more pipe conveyors will be planned and installed during the next decade in these areas. It will make south east Asia, Australia and south America important new markets for pipe conveyors.

Besides its obvious benefits, pipe conveyors have additional costs and engineering difficulties compared to trough conveyors. Capital cost is generally double comparable to trough conveyors due to increased number of idler rollers, bigger drive size, and higher belt cost. Same is true for operating cost, due to increased power consumption. One of the main engineering and maintenance concerns is how to control the belt rotation, twist and collapse, especially when the conveyor routing has small radius curves. The engineering of long distance and high tonnage pipe conveyors requires specialized engineering know-now that is no readily available to the general practitioners in the material handling sector. How to ensure a reliable, economic and optimized design of pipe conveyor systems is important to the system engineer, components supplier, the user/client, and the pipe conveyor sector itself.

In this article, the Authors attempt to illustrate some analysis and recent progress that bears importance to the pipe conveyors.

Pipe Belt Design, Testing and Modeling

Pipe conveyor belt has a much greater influence on the conveyor system performance than trough belt does. The main factor is the pipe belt stiffness. As the belt is

rolled into the pipe shape from the flat shape, the intrinsic bending stiffness of the belt turns into the contact pressure on surrounding idler rolls. Higher belt stiffness will result in higher contact pressure. This gives the pipe belt more stability and better resistance to twist and collapse during horizontal and vertical curves. But the penalty is increased power consumption, increased belt tension and all related results like the necessity for stronger belt and larger drive size. From the design point of view, there is a balance in the belt stiffness to achieve for each individual project. If the conveyor routing is straight, there is no need to design a pipe belt with high belt stiffness. Lower power consumption and capital cost can be achieved. If the conveyor routing has a lot of horizontal and vertical curves with small curve radius, the belt stiffness should be increased accordingly to accommodate the bending effect for curves, so that the belt does not have excessive rotation, twist and collapse. It should be both the belt manufacturer and system engineer's responsibility to work together to determine the suitable belt stiffness for each installation. This is especially true for long overland pipe conveyors.

There are many different approaches in designing the belt stiffness. They generally fall into two categories: experimental method and numerical method. Otte et al. designed an experimental device to test the pipe belt (3). The device has the capability to tension the pipe belt and simulate the curves by moving the idler stations.

Early analysis of pipe conveyors are based on analytical simplification of the pipe belt behavior. In recent years, the finite element analysis (FEA) is becoming more popular to simulate the pipe folding and curving behavior. Schilling et al. analyzed the fabric pipe belts with shell elements in ABAQUS (4). Imai et al. used solid elements to simulate the belt behavior under curves (5). However, the FEA of pipe conveyor belts is a highly nonlinear simulation and computationally expensive. Using coarse mesh with few elements, unrealistic boundary conditions and inaccurate material properties calibration will make the simulation results less than useful.

Conveyor Dynamics Inc. and Veyance Technologies Inc. together developed the Goodyear Confine[TM] steel cord and fabric pipe conveyor belts (patent pending). The Confine pipe belt has a unique cross section design, which is shown in Figure 1 and Figure 4 for the steel cord version. There are three different zones in the belt: a center tension carrying zone with steel cords, a overlap zone with reduced number of steel cords, and a junction zone with no steel cords. The design is a dramatic departure from the conventional design of evenly spaced steel cords across the belt width.

The center tension carrying zone lowers the center of gravity of the belt, because there are more steel cords. It makes the pipe belt more stable and resistant to rotation. The junction zone reduces the belt deformation and collapse during curves, because no bending forces from tensioned steels are existing in the junction zone. The overlap zone provides a tight seal of the pipe belt.

The development of Confine pipe belt involved both experimental and numerical methods. Extensive testing were carried out to verify the Confine belt construction. Figure 1. shows a 400mm nominal diameter, 1600mm wide ST1250 Confine steel cord pipe belt on a six point pipe belt stiffness testing device. There are six contact points on the folded pipe belt sample, where the contact force is measured as an indication of the belt stiffness. Figure 2 shows a three point bending stiffness testing device. The three point bending is a well defined bending test. Compared to the six point stiffness test, it is much easier to make test samples and generate design libraries based on the three point bending test. Once good numerical and experimental correlations between the three point bending stiffness and the six point pipe belt stiffness are established, there is no need to make full width belt samples and go through a trial-and-error process for each design before the actual belt production.
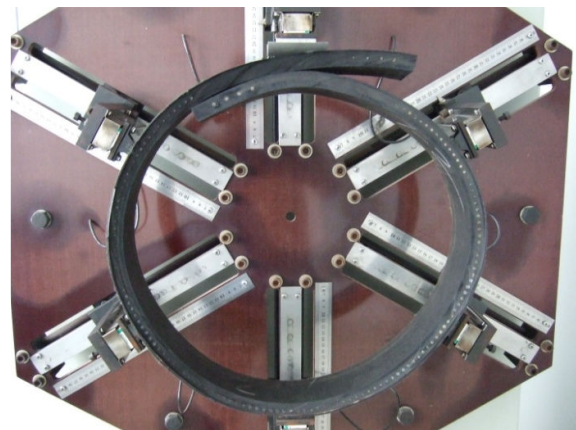

Figure 1. 1600mm wide ST1250 Confine Pipe Belt

Figure 2. 3 point bending stiffness test

Figure 3 shows a pipe belt transition test, to verify that the Confine belt construction can withstand severe transition between the flat belt to the folded belt.

Figure 3. Pipe belt transition test

Finite element analysis (FEA) is also used extensively to aid the design of the Confine pipe belt. Unlike other published FEA of pipe belts, where simplified shell or sold elements are used to represent both rubber, steel cord and fabric materials, a more complete model where the rubber, steel cords and fabric layers are modeled individually with their own material properties is used. The overall bending behavior of the pipe belt in FEA is compared and calibrated with three point bending and six point stiffness testing results. Figure 4 shows such a FEA model of a 500mm diameter ST4000 pipe belt. With FEA, various operating scenarios can be simulated. Pipe belt carrying material can be modeled, to examine the effect of belt sag and belt deformation from material loading. Different belt tension and its effect on overlap opening can be studied. More importantly, it enables us to compare different belt constructions and make design choices. The fidelity of the modeling can be seen in Figure 5, where an actual Confine pipe belt shape is closely compared to the FEA model.
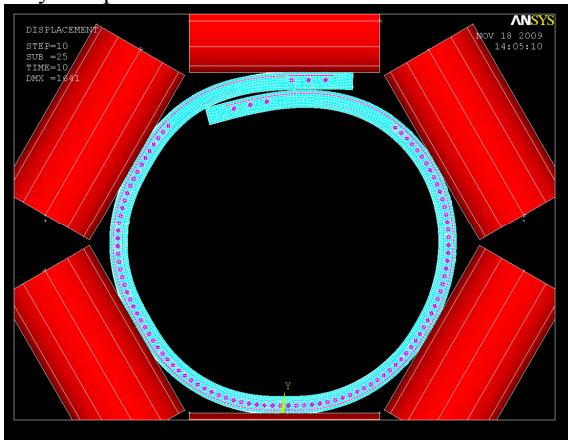

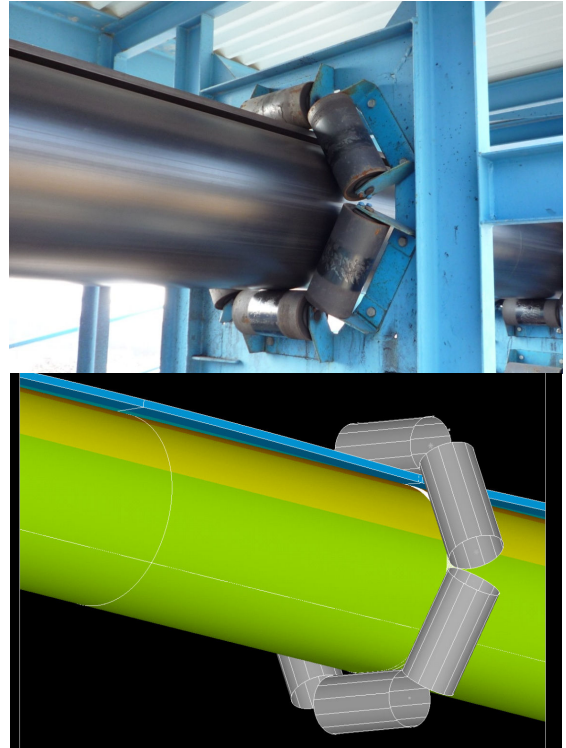**Figure 4**. FEA of 500mm ST4000 Confine Pipe belt

Figure 5. Comparison of a 400mm ST1250 Confine pipe belt with a FEA model of the same belt.
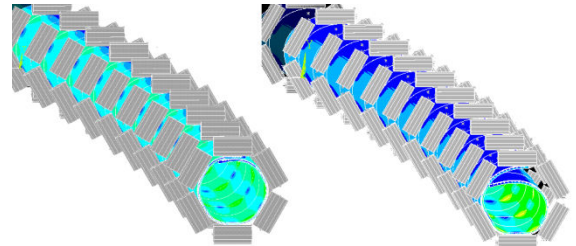

Figure 6. FEA simulation of Confine (left) and conventional (right) pipe belt during horizontal curves

Modeling of the pipe belt during horizontal and vertical curves provides the tool to analyze the proper pipe belt stiffness required for curves. Figure 6 shows a conventional steel cord pipe belt deforms at horizontal curves due to the bending effect of the tensioned belt (right image). The pipe belt loses contact with the idlers and its diameter decreases. If the belt stiffness increases, such deformation will decrease. The pipe belt construction also affects the belt behavior during curves, where the Confine belt is optimized to provide better resistance to deformation, twist and rotation even with the same belt stiffness (left image). Modeling pipe conveyor belt behavior during curves is quite complex, in addition

to the complexities of modeling and calibrating individual materials like rubber, fabric and steel cords. Such demanding simulations become feasible only in recent years due to the fast growth in computing power with decreasing cost.

Applications of the Confine Pipe Belt

Ever since the launch of the Goodyear Pipe Belt Project in 2008, over 40km long of Confine steel cord and fabric pipe belts have been installed and running successfully. Besides regular belts, special types of pipe belts are also engineered to meet the client's need. Figure 7 shows a 400mm diameter ST1100 pipe belt with Low Rolling Resistance (LRR) pulley cover compound, installed in a power plant in Bulgaria. The conveyor length is about 2.7km. The application of LRR pipe belt is reduces the power consumption and belt tension. To the Author's knowledge, this is also the world's first LRR pipe conveyor belt. For long overland pipe conveyors, every 10% reduction in power consumption will have significant impact on the system capital cost and operating cost, as is well demonstrated in overland trough conveyors (1, 6).

Figure 7. 400mm diameter ST1100 Low Rolling Resistance Pipe Belt

Heat resistant pipe conveyor belt adds the variable of wide temperature range to the conveyor belt engineering. As the pipe belt transports hot material, elevated temperature will decrease the belt stiffness. When the belt is empty, the belt stiffness increases with reduced temperature. The investigation of the belt stiffness variation with temperature, and how the stiffness variation affects the belt tension and conveyor power consumption, requires extensive testing and calculation. The rolling resistance of the heat resistant rubber compound also affects the calculation, because its viscoelastic property is different from the regular pulley cover rubber compound.

Figure 8 shows a 2-flight, 4km center-center length 350mm diameter heat resistant EPDM (Solarshield®) pipe belt. The maximum material temperature is 180°C. The first 3.4km long flight has a ST2000 steel cord belt. The second flight has a ST630 steel cord belt. Figure 9 shows two parallel 300mm diameter heat resistant EPDM fabric pipe belts with breaking strength of 800N/m. The material temperature is also 180°C. The third conveyor has a regular temperature 400mm diameter fabric pipe belt with 800N/mm breaking strength.

Figure 8. 350mm diameter ST2000 EPDM heat resistant pipe belt, with material temperature 180 °C

Figure 9. Two parallel 300mm diameter heat resistant Confine fabric pipe belts and a 400mm diameter Confine fabric pipe belt.

Dynamic Analysis and System Optimization

Conveyor Dynamics, Inc. developed a more fundamental approach to calculate the belt tension and power consumption for pipe conveyors. First, the pipe belt stiffness is determined based on the maximum belt tension and smallest curve radius, to prevent excessive belt rotation and twist from happening, and prevent high power requirement from excessive belt stiffness. From this optimized belt stiffness, contact pressure on the idler roll can be obtained based on FEA and experimental data. This contact pressure changes with belt tension, material loading and conveyor profile. Secondly, the viscoelastic properties of the rubber compound are measured on the Dynamic Mechanical Analysis (DMA) machine. From the viscoelastic properties and contact pressure, the indentation loss over each idler can be calculated. This methodology approaches the problem of calculating pipe conveyors from fundamental physics, rather than based on empirical relations. It allows design optimization based on LRR and design for specialty belts like the heat resistant pipe belts, because the range of design problems that can be addressed is much wider.

Conveyor Dynamics, Inc. has been a world leader in applying dynamic analysis to conveyor design ever since mid 1980s. Dynamic analysis is a powerful tool to simulate the conveyor starting and stopping behavior. Figure 10 shows the belt velocity vs time in an emergency stop for a 3km center-center long 600mm diameter pipe conveyor transporting. Under different loading conditions (empty and full, incline and decline loaded) and friction conditions (low friction and high friction), the stopping time can be very different. Dynamic analysis is based on the static analysis results, where the conveyor calculation is based on the steady state conditions. The dynamic analysis enables the system designer to look at different options of starting and stopping control to mitigate potentially dangerous shockwave from the sudden loss of motor power, reduce excessive high belt tension during starting, design safe and reliable stopping mechanism for a downhill conveyor, synchronize the stopping of upstream and downstream conveyors, etc. The general material handling sector is also beginning to realize the importance of dynamic analysis. Many system user now demand dynamic analysis to be included in the engineering phase of the conveyor system. As pipe conveyors grow in length and tonnage with more complex routing, the dynamic analysis becomes more important in the system engineering.
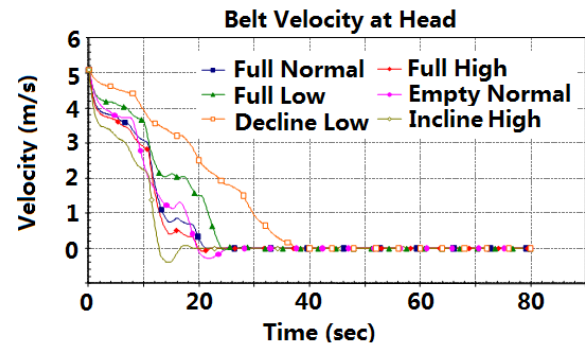

Figure 10. Dynamic analysis of pipe conveyor starting

Summary

A few important topics on the pipe conveyor belt and system are discussed in this paper, in particular relating to the patented Goodyear Confine Pipe conveyor belt. Experimental testing and numerical simulation on pipe conveyor belt are reviewed. Field installations with specialty belt like low rolling resistance belt, heat resistant belt are also shown as successful applications of the Confine pipe belt. With low rolling resistance belt, better understanding of the mechanics of the pipe belt and pipe conveyor system, and better system control from dynamic analysis, long overland pipe conveyor systems can become more competitive and reliable.

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