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Analysis on the Bending Stiffness and the Form Force of the Pipe Conveyor Belt

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Abstract: The bending stiffness and the form force of the pipe conveyor have a grate influence on the performance of conveyor belt into tube, the wear and tear of conveyor belt, running resistance and stability for pipe conveyor. This paper analyzes the stiffness distribution and the force behaviour of the pipe conveyor belt and designed a test-rig used for detection of the form force of the conveyor belt. The maximum tension of the conveyor belt can afford and the minimum curve radius of the conveyor belt can bend can be obtained，which can ensure the required form stability of the belt and prevent the belt from collapsing or buckling in curves. This test-rig provides reference tools for the selection of pipe conveyor belt and the design of belt conveyor. *Copyright © 2013 IFSA.*

Keywords: Pipe conveyor belt, Bending stiffness, Form force, Test system for bounce forces of the pipe conveyor belt.

1 Introduction

The pipe conveyor is a new type of belt conveyor equipment based on the trough belt conveyor, which not only have compact structure, small cross section, economic space, but also can be transmitted along the space curve. As a kind of environment-friendly continuous conveying equipment, the pipe conveyor is easy to realize pollution-free transport and airtight transport, and the deviation of the conveyor belt can not occur. It is widely used in industry such as ports, metallurgy, building materials, electric power, papermaking, and petroleum chemical, etc, which is used for transporting the material such as coal, raw coal, coke, blending material, sinter, petroleum coke, limestone, sand stone, calcium carbide slag, add wet ash, chemical fertilizer, salt, waste paper, phosphorus gypsum and pyrite slag [1].

According to the incomplete statistics, so far the domestic total production of the pipe conveyor is about more than 300 units, whose total length reaches 190 km. The maximum diameter of the pipe conveyor is 500 m and the minimum diameter is 150 m. With the transmission distance up to 7102 m, the route contains all kinds of complicated routes, such as the horizontal curve, the vertical curve, the s-shaped curve and the space curve [2-3].

The pipe conveyor is not stable enough during operation, whose problems are mainly concentrated in the roller, the conveyor belt and damage of the frame structure, especially is the damage of the conveyor belt. The pipe conveyor belt repeats the action of opening and closing in the process of operation, which has some higher requirements compared with the traditional slotted conveyor belt. It is generally believed the pipe conveyor belt should meet good flexibility to adapt to the bending deflection of curve section of small radius at runtime, good groove to remain the circular form stability in the process of running, good sealing ability to form good lap in the flexible edge preventing the dust escape, the stability of the dynamic load characteristics in the process of opening and closing the conveyor belt, Which can improves the lifetime of the conveyor belt. In some special occasions, it also require special performances such as requires wear-resisting, heat-resistant, fire-preventing, oil-preventing, explosion-proof. These performances request for theoretical research on running resistance, bending radius of belt conveyor and on the form force of the conveyor belt. It also request for experiment research on the structure of conveyor belt, the longitudinal and transverse stiffness (especially the transverse stiffness). The aim of research is to improve the working life and the reliability of the conveyor belt [4]. This paper makes theoretical analysis and experimental study on the transverse bending stiffness and the form force of the pipe conveyor belt.

The bending stiffness and the form force of the pipe conveyor have a grate influence on the performance of conveyor belt into tube, the wear and tear of conveyor belt, running resistance and stability for the pipe conveyor [5-6]. The transverse bending stiffness of the conveyor belt depends on the characteristics of the conveyor belt, which can also affect the resistance caused by pipe shaping, namely the forming force. If these form forces are too small, the edges of the belt could collapse. If these form forces are too high, the pipe belt aspires to open itself between the idler panels [7]. A minimum bending stiffness of the belt is necessary, to ensure the required form stability of the belt and to prevent the belt from collapsing or buckling in curves. From the demands for a minimum running resistance, a good shaping behaviour and good form stability, divergent requirements result in the quantity of the bending stiffness.

2. Theoretical Analysis on the Stiffness Distribution and the Form Force Behaviour

2.1. Theoretical Analysis on the Stiffness Distribution of the Conveyor Belt

Different stiffness impinges upon conveyor belts, depending on the belt guidance. On the one hand, they are caused by the belt tension. On the other hand, they take on additional stiffness resulting from the belt guidance itself.

Because of the additional elongation, the belt stiffness increase to the outer region of the belt starting from a neutral zone in the middle of a belt, while they decrease to the inner region of the belt [8]. Fig. 1 indicates the stiffness distribution inside the belt, which guided in a horizontal curve. The appropriate guidance is divided into four different sections.

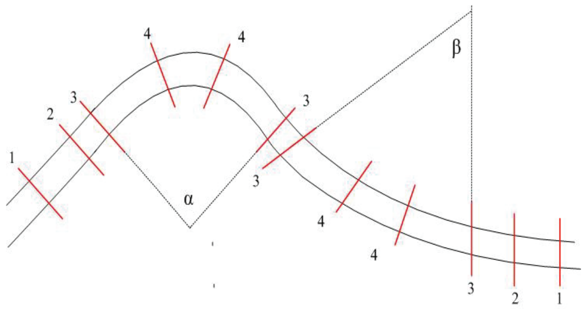

Fig. 1. The stiffness distribution inside the belt.

Section 1 is on the straight, far ahead or behind of the curve. The belt stiffness in this section caused by the belt tension in the system and is constant over the belt width. In section 2, just in front of and behind the curve is different over the belt width. The additional stiffness results from the elongation compensation in the reinforcement and extends far out of the curve, dependent on the belt guidance. Section 3 on the beginning or the end of the curve, which is similar stiffness distribution. The stiffness differences between the inner and the outer region of the belt are more distinct than in section 2. Section 4 is in the middle of the curve. In this section, the belt stiffness, conditioned by the belt tension, is superimposed by the maximal elongation in the outer region of the belt and the maximal compression in the inner region of the belt. This section is the critical area for the functional reliability, the stiffness distribution over the cross section of the pipe conveyor can be regarded as constant.

2.2. Analysis on the Form Force of the Conveyor Belt

The conveyor belt of the belt conveyor suffers a lot of forces, which can be divided into four forces: the tension force, the vertical force, the bending resistance force and the form force. As shown in Fig. 2, the tension force F_t occurs in the belt running direction.

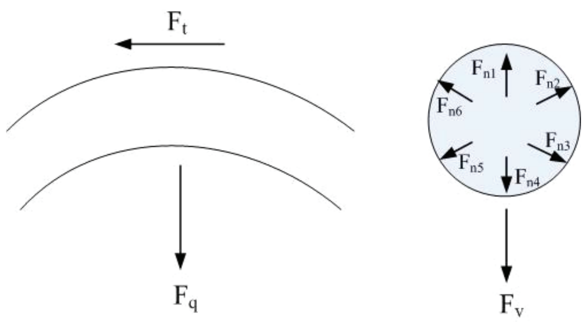

Fig. 2. Analysis on the forces suffered on the conveyor belt.

The vertical force F_v consists of the weight of the belt and the weight of the conveyed material. The bending resistance force F_q results in curves from the belt tension as well as the curve radius itself and points to the curve centre. The form force F_O points to the idlers which are arranged in a hexagon. These normal forces F_{ni} describe the sum of the components of the vertical force, the lateral force and the form force on each idler.

3. The Test Rig of the Form Force

The bending stiffness and the associated form forces of a pipe belt are significantly influenced by the belt construction. After theoretical preliminary work, a test rig was designed and constructed to determine the form forces of pipe belts under operating conditions, as shown in Fig. 3. According to the conditions of a real pipe conveyor, the parameters such ad pipe diameter, curve radius and belt tension can be adjusted. It can simulate the conveyor route, straight and horizontal curve. This test rig consists of three test system for bounce forces of the pipe conveyor belt and two hydraulic cylinders. By constantly adjusting the position of three test systems and two hydraulic cylinders, curvature radius of the conveyor line can be adjusted, which make the conveyor line horizontal curve. By adjusting the hydraulic cylinder, the tension of the conveyer belt can be adjusted. Six sliders on the hexagonal flat in the test system can imitate hexagon roller of conveyor belt.

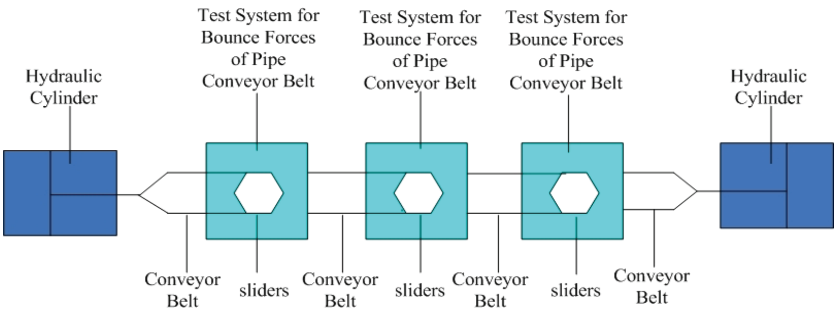

Fig. 3. The test rig for the form force of the pipe conveyor belt.

The test system for bounce forces of pipe belts of pipe conveyor is as shown in Fig. 4, consists of two parts, test instrument and computer and special software [9]. The test instrument is divided into four parts: the vertical test platform, the data processing and display circuit, the base plate of tester and the back of test platform.

1) The vertical test platform.

The base plate of vertical test platform is a processed hexagonal flat by machine using high-density rubber board, 12 mm thick, fixed in front of test platform with bolt and sleeve. The slide composed of biaxial parallel and matched with linear bearing, is uniformly distributed on the plate, a dot at the center of the plate. Along the slide is the slider, load cell installed on the slider. On the hexagon plate the longest distance between two diagonal sliders is 700 mm. The load cell sliding installed on the slider, consist of high-precision load cell, special contact of load cell, sensor cover of stainless steel, base plate for sensor installation. The force test component they formed is the core of the vertical test platform, while the vertical test platform is the core of the tester. The force Measured by the sensor is send to the data processing and display circuit in the form of millivolt level voltage signal for data processing and display.

2) The data processing and display circuit.

The analog signals measured by the force sensor are sent to the data processing circuit for A/D conversion to implement digitization.

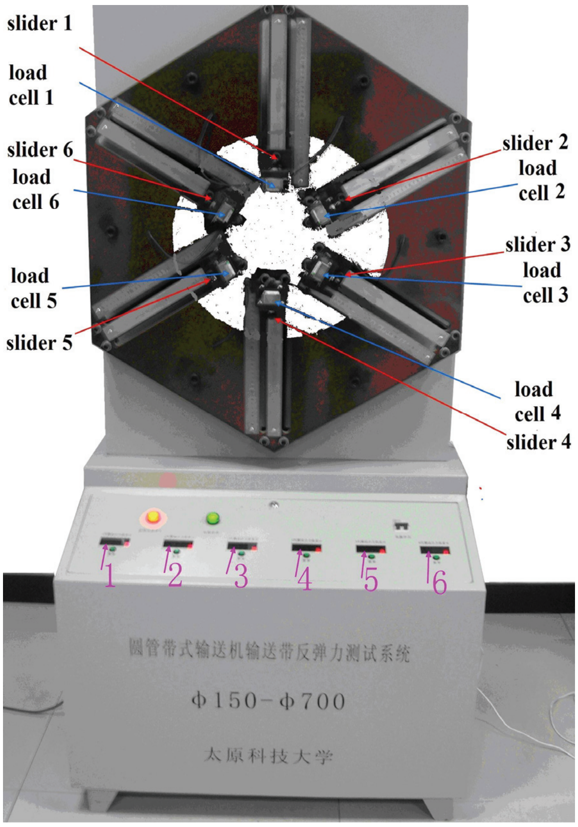

Fig. 4. The test system for bounce forces of the pipe conveyor belt.

A/D circuit is composed of 89C52 single chip micro computer and special software and other integrated circuit, which has the very high technology content and advanced data processing functions. The analog signal proportional to the bounce force of the conveyor belt will be processed for the digital signal in this circuit. Then it is sent to the six LED display to show a forth value. At the same time it is sent to the first computers for data entry, storage, printing, and management.

3) The base plate of the tester.

The base plate of the tester is the lower box and the support part, whose corners at the bottom have fixed support. And it also has a height adjustable activity leg to can adjust height, which is easy to obtain horizontal installment. The power switch, the entrance power light, the power on indicator, the display window of # 1 ~ # 6 force value measured and six corresponding reset button are installed on the upper part of the body. The electrical baseboard inside the top panel is fixed with six pieces of digital processing and display circuit. The reset button is used for the zero setting, when measuring point did not feel the rebound, but digital display window is not zero. Inside the box at the bottom of tester foundation is the box, which equipped with a dedicated power module for the digital processing circuit, to provide quality stable DC 5 V and DC 12 V power for six data processing and display circuit. In addition the power inlet of the tester, the entrance of the data line and connection terminals are installed in the box.

4) The special dynamometry software.

The special dynamometry software is an important part of this system, which retrieves force value processed by six data processing display circuit, and display in the corresponding window. It can make secondary processing according to the needs of the test data, such as: calculate the average, storage, check, etc, and can form test report with a special format for printout.

4. The Test Analysis

4.1. The Normal Force Behaviour of the Conveyor Belt with Change Tension

On this test rig, the tension of conveyor belt C is adjusted with the same curve radius to observe the normal force behaviour. The normal force of the belt C for increasing belt tensions is given in Table 1. In a horizontal curve with a curve radius of 300 m, the belt C was impinged with different belt tensions. F_{n1}, F_{n2}, F_{n3}, F_{n4}, F_{n5}, F_{n6} mean respectively the normal force of the conveyor belt measured by load cell 1, load cell 2, load cell 3, load cell 4, load cell 5, load cell 6 fixed on the test platform.

Table 1. The normal force behaviour of the conveyor belt C with a curve radius of 300 m.

Tension (kN) \ Normal Force (N)	F_{n1}	F_{n2}	F_{n3}	F_{n4}	F_{n5}	F_{n6}
0	300	500	520	900	420	0
100	250	450	420	910	150	0
200	250	600	520	1000	0	0
300	250	700	600	1010	0	0
400	250	780	700	1020	0	0
500	250	850	750	1050	0	0

With rising belt tensions F_t from 0 to 500 kN, the normal forces F_{n2} on the inner slider 2 increase from about 500 N up to 850 N. At the beginning of the test the pipe belt impinges 420 N on the slider 5 without a belt tension. The belt is not in contact with the slider 5 at a belt tension of 200 kN. Consequently, the normal forces on idler 4 increase from 1000 N to 1050 N, which take up the entire vertical force of the conveyor belt. This method is also used to test other conveyor belt, such as conveyor belt A and conveyor belt B. The maximum tension of the conveyor belt can afford can be obtained from the test with the required form stability.

4.2. The Compassion of the Normal Force of Different belt with Different Curve Radius

For different conveyor belt, the normal force behaviour is compared through different curve radius. The normal force behaviour of different belt with belt tensions is 300 kN and different curve radius given in Table 2, Table 3 and Table 4, which is horizontal curve towards right.

For three different conveyor belt, the normal force of inner slider increase with decreasing curve radius, which is shown in Table 2, Table 3 and Table 4.

Table 2. The normal force behaviour of conveyor belt A with a belt tension is 300 KN.

Normal Force (N) / Curve radius (m)	F_{n1}	F_{n2}	F_{n3}	F_{n4}	F_{n5}	F_{n6}
straight	25	40	30	130	70	20
1000	30	40	40	130	40	0
700	30	50	50	150	0	0
500	25	60	160	200	0	0
400	25	80	250	230	0	0
300	30	120	250	260	0	0

Table 3. The normal force behaviour of conveyor belt B with a belt tension is 300 KN.

Normal Force (N) / Curve radius(m)	F_{n1}	F_{n2}	F_{n3}	F_{n4}	F_{n5}	F_{n6}
straight	30	30	80	150	80	40
1000	40	40	90	160	50	0
700	40	40	100	180	20	0
500	20	50	140	200	0	0
400	50	100	160	210	0	0
300	60	150	180	250	0	0

Table 4. The normal force behaviour of conveyor belt C with a belt tension is 300 KN.

Normal Force (N) / Curve radius (m)	F_{n1}	F_{n2}	F_{n3}	F_{n4}	F_{n5}	F_{n6}
straight	200	250	250	900	250	250
1000	200	400	300	950	300	0
700	210	420	300	900	190	0
500	220	400	300	1000	190	0
400	210	480	480	1000	310	0
300	250	700	600	1010	0	0
200	300	750	700	1050	0	0

During the tests of the conveyor belt A and B in a straight guidance and in curves with the radius of 1000 m and 700 m, only small normal forces of 50 N occur on the inner sliders. These belts constrict themselves due to the belt tension, which leads to smaller normal forces on the idlers, compared to the belt construction C. A similar constriction resulting from the belt tension at the belt A and B does not appear within the tests of the belt C.

When the curves radius of conveyor belt is 700 m, the belt A has no contract with exterior slider 5 and 6, which illustrate the minimum curve radius of the conveyor belt can bend is 1000m with required form stability of the belt. The same method is used for belt B and C. The test indicates that the conveyor belt C has more bending stiffness than belt A and B.

5. Conclusions

During the design of pipe conveyors, the choice of a suitable belt is very important. If the character of the belt is determined, the bending stiffness of the belt and thus the reliability of the entire conveyor system are determined [10-12]. If the bending stiffness is too low, the inner belt edge might immerge into the transported material and throw it out into the discharge area. Moreover, the pipe belt could collapse in curves because of the occurring lateral forces. A safe transport of bulk solids could not be ensured. If the bending stiffness is too high, a pipe belt aspires to open itself between the idlers. From the demands for a good shaping behaviour and shape stability at the same time as well as a minimum running resistance, these requirements result in the quantity of the bending stiffness.

The bending stiffness of the belt was experimentally determined at different parameters such as curve radius, belt tension, environmental temperature and the character of the bulk solids. For this purpose, a pipe belt test rig was built. Through it, the normal forces of pipe belt on the idlers at different belt tensions can be determined, the maximum tension of the conveyor belt can afford and the minimum curve radius of the conveyor belt can bend can be obtained with required form stability. Tests were carried out at different pipe belt A, B, C. The belt C showed the highest bending stiffness. The belt A and B showed s a lower level than the belt C. The normal forces on the inner idlers increased with decreasing curve radius and increasing belt tensions. They lost contact to the outer idlers when the curve radius decreases to certain quantity and the tension increase to certain quantity, hence they were not guided by these idlers anymore. Such the maximum tension and the minimum curve radius with required form stability can be determined.

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