Form Force Behaviour of Pipe Conveyors in Different Curve Radii

S. Hötte, L. Overmeyer, and T. Wennekamp, Germany

For a reliable operation of the pipe belt, the bending stiffness in transverse direction has a great importance. Form forces should neither be too small, not too high. Moreover, 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. In the context of a research project in cooperation between the Phoenix Conveyor Belt Systems and the Institute of Transport and Automation Technology (ITA) the distribution of the belt stiffness resulting from the belt construction and the minimal feasible curve radii was determined, and a test rig was designed to examine the form forces of the belt dependent on certain conveyor belt and plant parameters.

Key Words: *pipe conveyor, belt stiffness, belt stress, test rig*

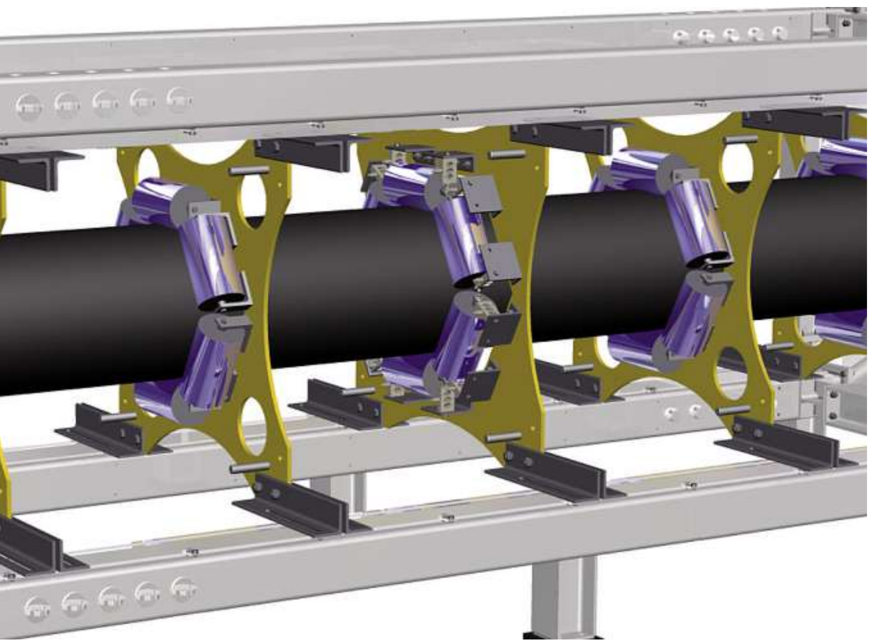

Fig. 1: Test rig designed to examine the form forces of the pipe belt.

1 Introduction

With a history of approx. 30 years, the pipe conveyor is a proven and well established means for transportation of bulk solids. Compared to conventionally troughed belt conveyors, the rolled-up and closed shape of the pipe belt creates a variety of specific advantages and disadvantages. A decisive advantage results from the topology-flexibility of pipe conveyors. In comparison to conventional conveyor belts, three-dimensional curves with significantly smaller curve radii and higher slopes can be realised. Because of the shape of the pipe belt enclosing the bulk material, immission and emission are impeded.

For a reliable operation of the pipe belt, the bending stiffness in transverse direction, depending on the belt construction, has a great importance. Form forces, resulting from the bending stiffness, keep the belt in its closed form. If these form forces are too small, the edges of the belt could collapse. A safe transport of bulk solids could not be ensured. If these form forces are too high, the pipe belt aspires to open itself between the idler panels.

In this case, the friction among the edges of the belt in the overlap leads to a higher running resistance and a reduced energy-efficient mode of the pipe conveyor. Moreover, 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 a high form stability, divergent requirements result with regard to the amount of the bending stiffness.

For this reason, in the context of a research project in cooperation between the Phoenix Conveyor Belt Systems and the Institute of Transport and Automation Technology (ITA), the distribution of the belt stiffness resulting from the belt construction and the minimal feasible curve radii was determined. For this purpose, a test rig was designed to examine the form forces of the belt dependent on certain belt and plant parameters (Fig. 1). Therefore, different belt constructions are investigated concerning their form stability at varied belt tensions and adjustable curve radii.

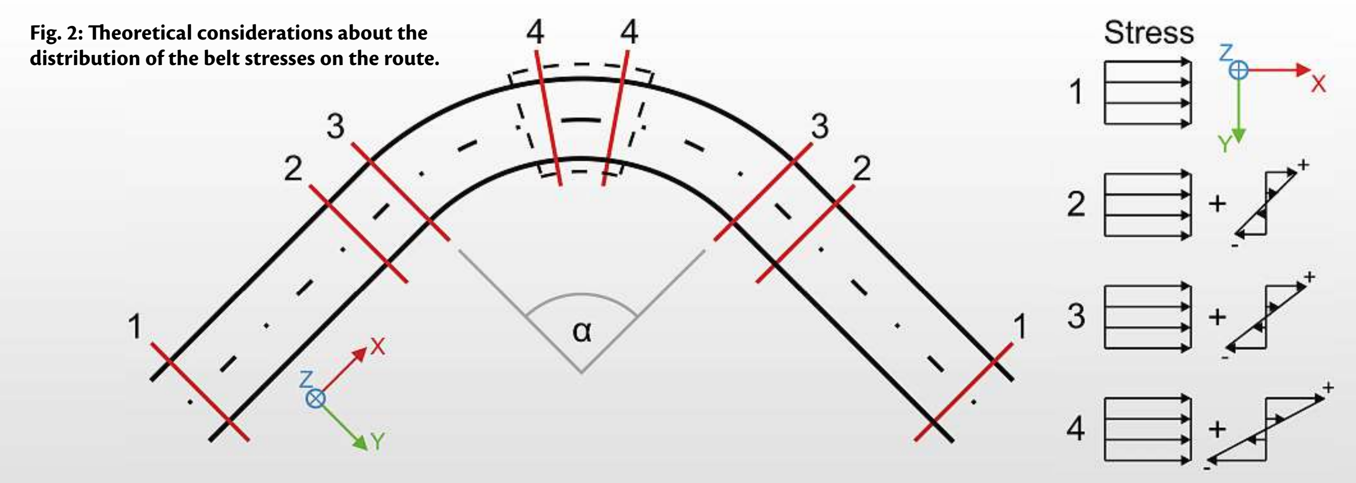

Fig. 2: Theoretical considerations about the distribution of the belt stresses on the route.

2 Pipe Conveyor Basics

As stated before, for a reliable operation of the pipe belt, the bending stiffness in transverse direction, depending on the belt construction, has a great importance. The deformation of the flatly produced belt to the rolled up pipe results in form forces caused by the bending stiffness, which is necessary to keep the belt in its closed form.

If the form forces are too small, the edges of the belt could collapse. A safe transport of bulk solids could not be ensured. If they are too high, the pipe belt aspires to open itself between the idler panels. In this case, the friction among the edges of the belt in the overlap leads to a higher running resistance and a reduced energy-efficient mode of the pipe conveyor. Moreover, 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 [1 and 2]. From the demands for a minimum running resistance, a good shaping behaviour and a high form stability, divergent requirements result in the quantity of the bending stiffness. The request for pipe conveyors with larger mass flows and hence greater pipe diameters is steadily increasing.

For the investigation of the bending stiffness, resulting from the belt construction and the minimum feasible curve radii, a test rig was designed in the context of a research project in cooperation with the Phoenix Conveyor Belt Systems and the Institute of Transport and Automation Technology. With this test rig, the form forces of pipe conveyors on the idlers can be determined under operating conditions, dependent on certain belt and plant parameters.

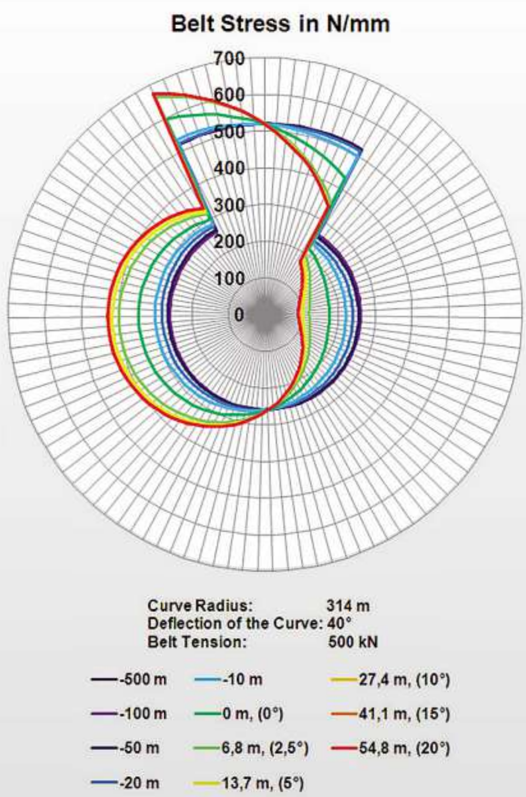

Fig. 3: Distribution of the belt stress in a pipe belt on the route.

3 Considerations on Belt Stresses

Different stresses impinge upon conveyor belts, depending on the belt guidance. On the one hand, they are caused by the belt tension of the system, on the other hand, they take on additional stresses resulting from the belt guidance itself [3]. To realise a realistic stress distribution across the belt width in the pipe conveyor test rig, it is of a great importance to set the belt tension in each cord of the reinforcement, in accordance with the conditions of an operating belt.

Starting from a neutral zone in the middle of a belt, the belt stresses increase to the outer region of the belt because of the additional elongation, while they decrease to the inner region of the belt. Fig. 2 explains the stress distribution inside a belt, guided in a horizontal curve. The appropriate guidance is divided into four different sections. Section 1 is on a straight, far ahead or behind of the curve. The belt stresses in this section are caused by the belt tension in the system and are constant over the belt width.

In Section 2, just in front of and behind the curve, these stresses are superimposed by a stress distribution which is different over the belt width. These additional stresses result from

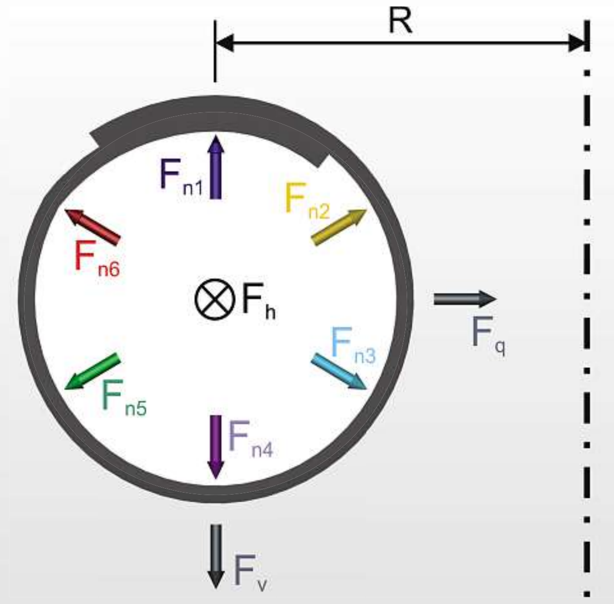

Fig. 4: Loads on the idlers of a pipe conveyor.

the elongation compensation in the reinforcement and extend far out of the curve, dependent on the belt guidance. A similar stress distribution appears in Section 3, the beginning or the end of the curve. Here, the stress differences between the inner and the outer region of the belt are more distinct than in Section 2.

The region of the middle of the curve is described in Section 4. In this section, the belt stress, 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.

In order to ensure a safe and reliable performance of the belt, this section is particularly critical. Basically, the pretension of the belt at the take up device should be sized sufficiently high so that compressive stress may not arise from the superimposition of the local belt stress, caused by the stress differences between the inner and the outer region of a belt in a curve.

In Section 4, which is the critical area for the functional reliability, the stress distribution over the cross section of a pipe conveyor can be regarded as constant.

Within this research project, the stress distribution of pipe conveyors along the belt guidance was studied first. For this purpose, a calculation basis for the determination of additional stresses and elongations was made by reference to the theoretical approaches of Oehmen [4 and 5].

Fig. 3 shows an example of the stress distribution of a pipe conveyor in the range from 500 m ahead of the curve up to the middle of the horizontal curve with a radius of 314 m and a deflection of 40 degrees. For the interpretation it should be noticed that the calculation method is based on a predetermined and idealized shape of a pipe belt, which is not deformed due to the occurring stresses.

Particularly noticable is the stress distribution in the overlapping area of the belt. Because of the belt edges, the stresses occur twice and therefore, double the stress in the overlap. At a distance of 500 m in front of the curve, the stress is distributed symmetrically with 260 N/mm to the vertical axis of the cross section. With the approach to the curve area, the stress increases in the outer region of the belt and decreases in the inner region of the belt.

In the area between 10 m ahead of the curve and 6.8 m, corresponding 2.5 degrees behind the entry of the curve, a significant change of the stress is recognisable. In the outer region of the belt, the stress increases from 300 to 400 N/mm. At a deflection of 5 degrees, the stress reaches 426 N/mm.

In the middle of the curve, the stress in the outer region of the belt equals 429 N/mm. Compared to the stress at a deflection of 10 degrees, the difference is less than 1 per cent. In the

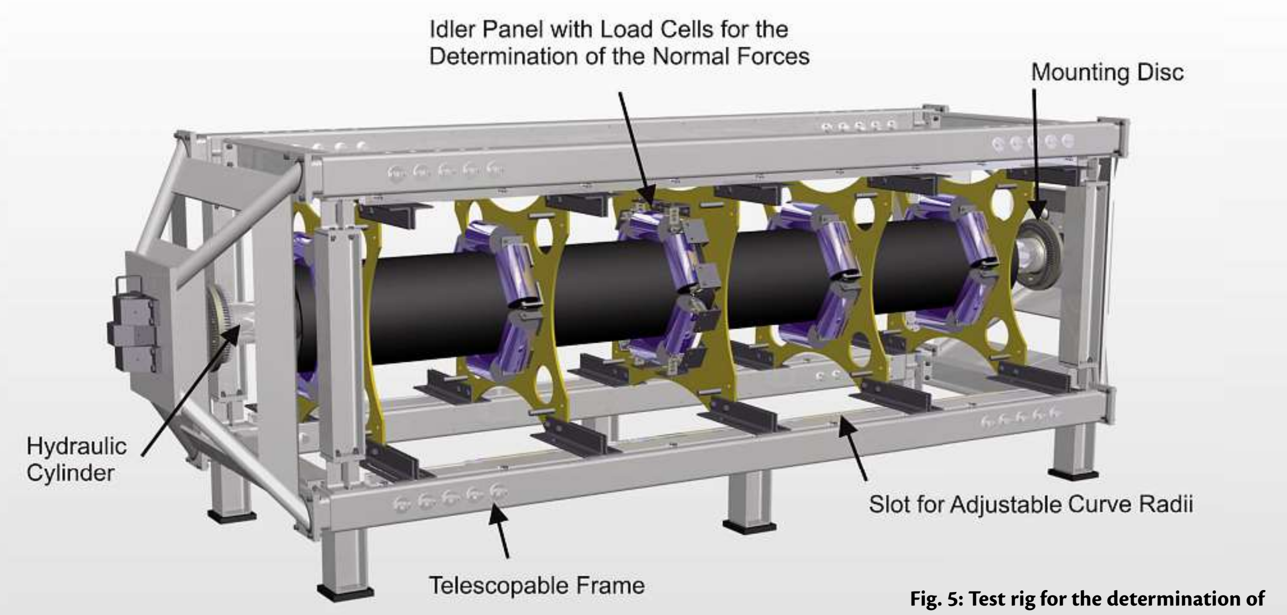

Fig. 5: Test rig for the determination of the normal forces of pipe belts.

inner region of the belt, the stress decreases to a minimum of 90 N/mm.

On the basis of this investigation, the stress distribution shows that the occurring stresses in the belt appear within a few meters from the curve entry and do not vary noteworthy in most of the span of the curve. The area of the greatest stress differences between the inner and outer region of the belt in the curve is therefore present on nearly the entire curve.

4 Test Rig for the Form Force Behaviour

Different loads impinge on a pipe belt within a belt conveyor. They can be divided into the three external forces horizontal force, vertical force and lateral force and the internal normal forces.

The horizontal force F_h occurs in the belt running direction and is equivalent to the belt tension. The vertical force F_v consists of the weight of the belt and the weight of the conveyed material. The lateral force F_q results in curves from the belt tension as well as the curve radius itself and points to the curve centre.

Fig. 4 summarises the forces occurring at a pipe belt. The inner forces point to the idlers which are arranged in a hexagon. These normal forces $F_{n,i}$ describe the sum of the components of the vertical force, the lateral force and the form force F_o on each idler.

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, see Fig. 5.

According to the conditions of a real pipe conveyor, the parameters pipe diameter, spacing of the idler panels, assembly of the idlers, curve radius and belt tension can be adjusted. The test rig consists of a modular and telescopable frame, so that the spacing of the idlers can be set between 1 and 2 m.

The pipe belt can be guided by up to five idler panels. The positioning of these idler panels emulates a given belt guidance in the test rig. The design allows the adjustment of horizontal and vertical curve radii with a minimum curve radius of 50 m.

The belt tension of up to 632 kN is provided by hydraulic cylinders. To implement different stress distributions over the belt width during the test of steel cord belts, it is possible to impinge on each cord with a specific tension. The cord ends are attached to mounting discs, which have a hole pattern that matches the cord positions of an ideal shape of a pipe belt.

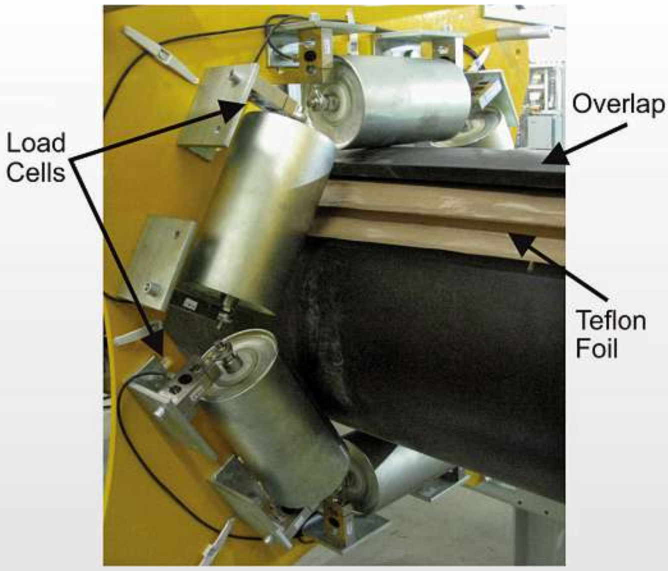

Fig. 6: Assembly of the load cells for the determination of the form forces.

The tension of each cord, which in curves depends on the distance to the neutral zone of the belt, can be set by the adjustment of threaded rods. The test rig allows the assembly of the idlers in a hexagon in one plane, or in two triangles rotated by 60 degrees in two planes.

The maximum examinable pipe diameter in the test rig is 850 mm. The normal forces are measured by load cells mounted on the idler panel, which is placed in the middle of the test rig. If necessary, this panel can be positioned at any point within the test rig.

Fig. 6 shows the assembly of the load cells for the determination of the normal forces. Moreover, teflon foil is recognisable in the overlap, which is used to reduce the friction in between the overlapping belt edges.

5 Form Force Behaviour

Concerning the behaviour of the form forces, various belt constructions were investigated in the test rig. Exemplarily, the results of three different belt constructions with the same nominal breaking strength and the same pipe diameter are presented here.

All tests were performed with a spacing of the idlers of 1 m. During the tests, the parameters belt tension and curve radius were varied. The determination of the normal forces was made with a minimum curve radius of 200 m and belt tensions from 0 to 500 kN.

Exemplarily, the normal force behaviour of the belt constructions for increasing belt tensions is given in Fig. 7. In a horizontal curve with a curve radius of 300 m, the belt construction C was impinged with different belt tensions. The normal forces $F_{n,i}$ are shown in the hexagon graph.

With rising belt tensions F_T from 0 to 500 kN, the normal forces $F_{n,i}$ on the inner idlers increase from about 500 N up to 830 N. While the pipe belt impinges 420 N on the idler 5 without a belt tension at the beginning of the test, the belt is not in contact any more with this idler at a belt tension of 200 kN.

Consequently, the normal forces on idler 4 increase, which take up the entire vertical force component of the outer belt region. This qualitative behaviour of the pipe belts was also determined during the tests of the belt constructions A and B.

For a comparison of the different belt constructions concerning various curve radii, Fig. 8 plots the normal forces for horizontal curves to the right at the belt tension of 300 kN. During all tests, the outer belt edge in the overlap pointed to the outside of the curve.

It should be noted that the axes of the diagrams of the belt constructions A and B illustrate maximum normal forces of 300 N, while the axis of the diagram of the belt construction C represents maximum normal forces of 1200 N.

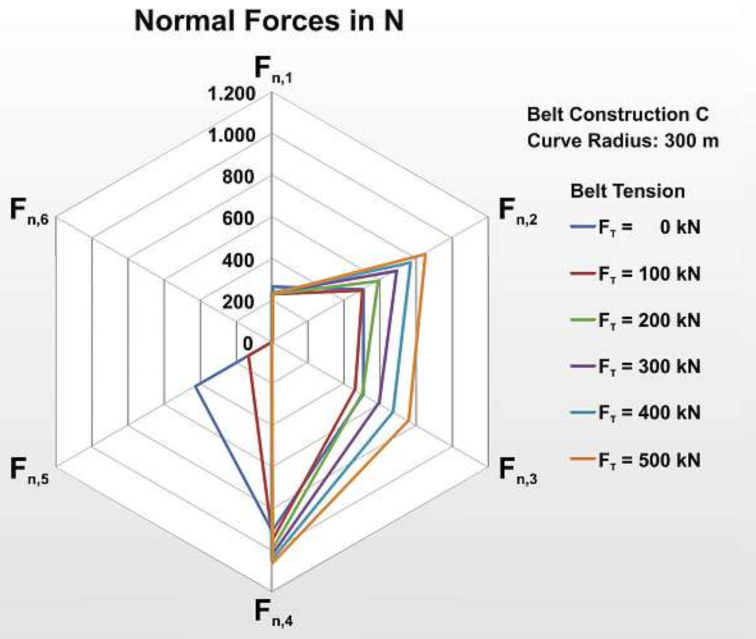

Fig. 7: Normal forces $F_{n,i}$ dependent on belt tension F_T.

For the three different belt constructions, the normal forces on the inner idlers increase with decreasing curve radii. During the tests of the belt constructions A and B in a straight belt guidance as well as in curves with the radii of 1000 and 700 m, only small normal forces of 50 N occur on the inner idlers. These belt constructions constrict themselves due to the belt tension, which leads to smaller normal forces on the idlers, compared to the belt construction C.

This is particularly distinct for the belt construction B and recognisable up to a curve radius of 400 m. The outer idlers have no

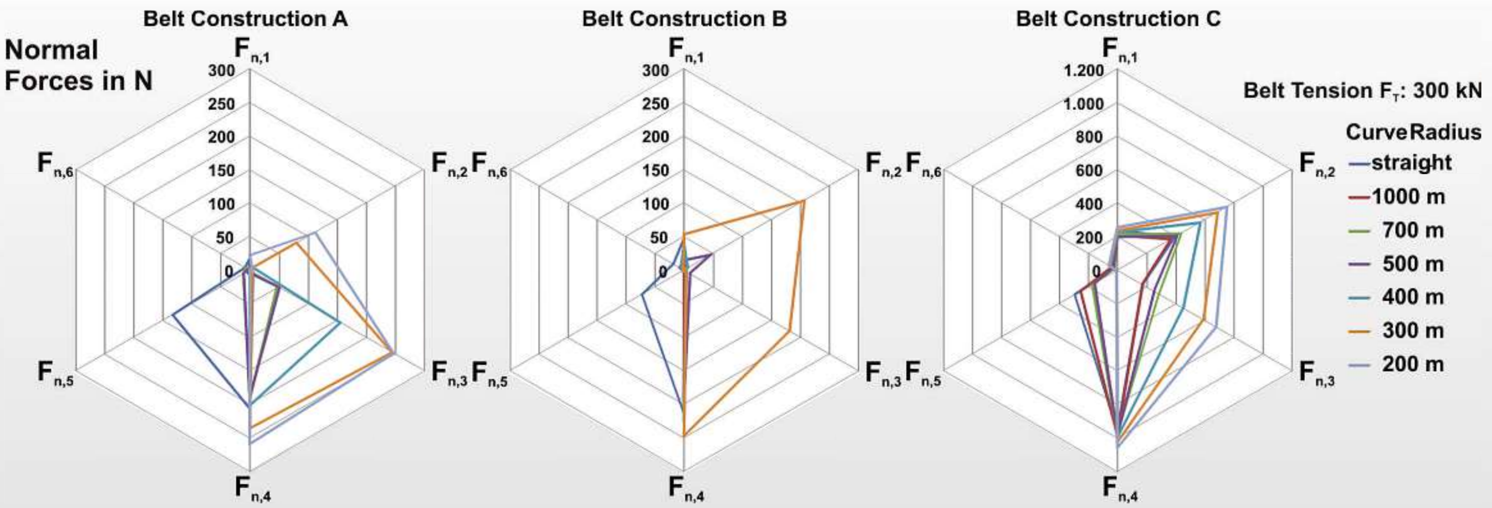

Fig. 8: Normal force behaviour of the belt constructions A, B und C at different curve radii.

contact with the pipe belt constructions A and B from a curve radius of 1000 m. The normal force behaviour of the belt construction C shows a comparably higher quantity of the bending stiffness of this construction. Even within a straight belt guidance, normal forces of about 260 N occur on idler 5.

At a curve radius of 500 m, 190 N are still supplied by the belt on this idler. About 240 N occur on the horizontally arranged idler 1 and about 1000 N on the horizontal idler 4. In comparison, the belt constructions A and B impinge approximately 200 N on idler 4.

The plotted forces on the inner idlers 2 and 3 of belt construction C give a good impression about the increasing normal forces due to decreasing curve radii. A similar constriction resulting from the belt tension at the belt constructions A and B does not appear within the tests of the belt construction C.

6 Summary and Conclusion

During the design of pipe conveyors, the choice of a suitable belt construction is of great importance. With the belt construction, the bending stiffness of the belt and thus the reliability of the entire conveyor system are determined. 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 in consequence 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 idler panels. In this case, the friction among the edges of the belt in the overlap causes a higher running resistance and a reduced energy-efficient mode of the pipe conveyor. From the demands for a good shaping behaviour and a high form stability at the same time as well as a minimum running resistance, divergent requirements result in the quantity of the bending stiffness.

For this reason, in the frame of a research project in cooperation with Phoenix Conveyor Belt Systems and the Institute of Transport and Automation Technology (ITA), the normal force behaviour of pipe belts was experimentally determined at different parameters such as curve radius and belt tension. For this purpose, a pipe belt test rig was built, which can determine the normal forces of real pipe belt specimen on the idlers at different belt tensions up to 632 kN.

Based on theoretical considerations of the different stress distribution across the belt width of pipe belts in curves it could be shown that these stresses can be adjusted and implemented, according to the operating conditions. Subsequently, tests were carried out at different belt constructions, of which the variants A, B and C are mentioned in this publication. All tests were performed up to a minimum curve radius of 200 m and a maximum belt tension of 500 kN.

The belt construction C produced the highest bending stiffness. The belt constructions A and B showed similar measurements, but were at a lower level than the belt construction C. It was shown that the normal forces on the inner idlers increased with decreasing curve radii and increasing belt tensions. At the same time, they lost contact to the outer idlers, hence they were not guided by these idlers anymore.

This pipe belt test rig allows comparative measurements of the normal forces at various operating parameters. Consequently, the belt construction can be compared in terms of their normal force and form force behaviour respectively their related bending stiffness. Based on the test results, the belt manufacturer is supported in the design and the selection of a suitable belt construction, concerning a reliable functionality and applicability for a pipe conveyor during the dimensioning process. ■

References

[1] Wiedenroth, J.: *Untersuchungen zum Betriebsverhalten unbeladener Schlauchgurtförderer*. Dissertation Universität Hannover, 1995

[2] Engst, W.: *Rollgurtförderer für Massenströme mit höherer Geschwindigkeit bei steilansteigender und kurviger Streckenführung*. Dissertation Universität Hannover, 1986

[3] Lodewijks, G.: *The Design of Conveyor Belting for Pipe Conveyors*. 9th International Conference on Bulk Materials Storage, Handling and Transportation, 2007

[4] Oehmen, K.H.: *Zur Berechnung zusätzlicher Dehnungen in Stahlseilgurten infolge Kurvenführungen und Muldungsübergängen*. Braunkohle 6 (1977), pp. 235 – 246

[5] Oehmen, K.H.: *Einfluß vertikaler und horizontaler Kurven auf die Dehnungsverteilung in Fördergurten – Theorie und Anwendung*. Braunkohle 10 (1979), pp. 340 – 348

About the Authors

Dipl.-Ing. Stephan Hötte

Institute of Transport and Automation Technology
Leibniz University Hannover
An der Universitaet 2,
30823 Garbsen, Germany
Tel.: +49 (0)511 762-181 77
Fax: +49 (0)511 762-400 7
E-Mail: stephan.hoette@ita.uni-hannover.de

Prof. Dr.-Ing. Ludger Overmeyer

Institute of Transport and Automation Technology
Leibniz University Hannover
An der Universitaet 2,
30823 Garbsen, Germany
Tel.: +49 (0)511 762-25 03
Fax: +49 (0)511 762-40 07
E-Mail: ludger.overmeyer@ita.uni-hannover.de

Dr.-Ing. Tobias Wennekamp

Phoenix Conveyor Belt Systems GmbH
Hannoversche Strasse 88
21079 Hamburg, Germany
Tel.: +49 (0)40 76 67-23 95
Fax: +49 (0)40 76 67-29 87
E-Mail: tobias.wennekamp@phoenix-cbs.com