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Measurement of a pipe belt conveyor contact forces and cross section deformation by means of the six-point pipe belt stiffness testing device

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ABSTRACT

This paper presents an experimental study that investigated the influence of major pipe conveyor parameters, such as pipe diameter, belt width, transverse bending stiffness, line mass and position of the belt overlap on the load distribution between the individual idler rolls, as well as the ability of the belt to form a stable pipe. The measurements were conducted using a static six-point pipe belt stiffness testing device. The results confirmed that bigger pipe diameters require higher bending stiffness to ensure the belt forms a stable pipe. The pipe diameter can be changed by either varying the length of the overlap, or by selecting a different belt width and keeping the ratio pipe diameter versus the belt width constant. More flexible belts require larger overlap for stable pipe shape. If the ratio belt width versus pipe diameter is constant for all manufactured belt widths, higher stiffness is needed for wider belts.

1. Introduction

Pipe belt conveyors are the most popular type of enclosed continuous bulk material transport systems. Their design guarantees reliable operations in difficult environmental conditions, and provides spillage-free conveyance of dusty, contaminated and other problematic bulk materials [1–3]. Moreover, pipe conveyors can be installed with spatially tight route curves and high inclination angles [4].

The load distribution between the idler rolls affects the operational behaviour of pipe conveyors. The contact forces identify the indentation rolling resistance, studied by Zamiralova and Lodewijks [5], Zamiralova et al. [6], Zhang [7]. This, in turn, affects the energy consumption and choice of the drive power of the system (e.g. see Wesemeier [8–10], Zhang [7]). Moreover, the contact forces determine the stabilizing rotary moment from the friction between the external surface of the belt and the idler rolls. This moment counteracts the undesirable twisting moment of the belt, which can appear in particular in the curves of the conveyor route.

Contact forces are inextricably linked to the geometry of the pipe conveyor cross section. The last one is a result of the highly nonlinear process of folding the belt from a flat shape into a pipe shape, see Fig. 1. The geometry of the cross section represents the mechanical response of the belt structure to the folding process. The geometry identifies the contact forces, the appearance of the contact loss between the belt and idler rolls, and the tendency of belt to collapse. Furthermore, the cross section deformation is involved in the rolling resistance component from the flexure of the belt and bulk material. The cross section geometry also plays an important role in the twisting

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Fig. 1. Folding belt from flat shape into a pipe shape. Image Courtesy of Specialty Welding & Fabricating of New York, Inc.

phenomena of pipe conveyors. As discussed by Lodewijks et al. [11], Zamiralova and Lodewijks [12], the pipe conveyor belt can be considered as an open thin walled structure. The geometry of the cross section defines the position of the shear centre, which in turn affects the rate of the generated longitudinal conveyor twist.

As discussed above, the contact forces and cross section geometry significantly contribute to the operation behaviour of the pipe conveyors. It is thus evident that these are important factors to consider, study and optimise.

A number of the researchers have dedicated their studies to the analysis of the load distribution between the idler rolls in respect to the cross section geometry of the belt. In general, these studies can be categorized based on the theoretical and experimental approaches. The first approach implies two possibilities: developing an analytical model, or, by means of the numerical calculation with a finite element model.

A number of researchers have developed models to determine the contact forces at the individual idler roll of the pipe conveyor idler station analytically (e.g. Dmitriev and Sergeeva [13], Sergeeva [14], Efimov [15], Wesemeier [16], Zamiralova et al. [17]). These models used the initially pre-folded pipe shape geometry of the cross section as a reference structure under the action of external loads. A preliminary analytical model was developed by Efimov [15], which was similar to the studies of Dmitriev and Sergeeva [13] and Sergeeva [14]. In order to describe the expansion load from the belt stiffness, that occurs due to the bending the belt from a flat shape into a pipe shape, the researchers [13–15,17,18] used an equivalent distributed load as proposed by Chernenko [19,20] and later by Wesemeier in [10,16]. The load from the bulk material in the literature [13–15,18] was prescribed according to Gushin's recommendations [21], which were developed for deep trough belt conveyors. Alternatively, Wiedenroth [22] proposed that the impact of the transported bulk material on the contact forces can be considered analogically to trough belt conveyors with an installation angle of the idler rolls of 60 degree, as was studied by Grimmer and Grabner [23].

The selection of the initial reference cross section geometry influences the resultant contact forces in the analytical models. For instance, in the studies [5,13–15,17,18], the cross section was simplified as a perfect circle with an opening on the top, which implies a symmetrical load distribution between the idler rolls. Zamiralova and Lodewijks [12] made an attempt to take into account the overlap geometry, by assuming the cross section as an Archimedean spiral. Therefore, in order to develop an appropriate analytical model, the initial belt configuration needs to be determined in a manner that represents its real geometry.

Apart from the analytical models, the problem has also been studied through the use of numerical methods that were implemented in software. Schilling et al. [24] solved the problem stepwise: first the belt structure was gradually folded from a flat shape into a pipe, and then all the other external loads were applied to it. A similar approach was used by Fedorko et al. [25], however, the study was focused on transition zones for moulding idler rolls. Wesemeier [8,9,16,26] also studied with finite element analyses the influence of the belt stiffness and tension on the belt deformation. However, the model was created for the vertical pipe conveyor, so the impact of the loads from belt weight and bulk material was not considered. Zhang and Steven [27] introduced a numerical model for pipe belt conveyor systems, by modelling the full complexity of the belt structure. The researchers Kulagin [28], Dmitriev and Kulagin [29], Sergeeva [14] also examined belt deformation and the appearance of the contact loss between the rolls and the belt, by applying the external loads onto an already pre-folded pipe shaped belt structure.

It is important to emphasise the significance of the experimental approach. Experiment results are required for validating both analytical and computational approaches. Moreover, as it was mentioned above, the selection of the reference geometry for both methods needs to be also verified through experimentation.

Zhang and Steven [27] described a new type of belt for pipe conveyors, reporting experimental testing by means of the static six point pipe belt stiffness testing device. The test rig was elaborated by Conveyor Dynamics Inc. together with Goodyear Engineered Products, Veyance Technologies Inc. and is illustrated in Fig. 2. However, there are no quantitative test results on contact forces measured are available in the source [27]. Similar test rig was used by Hötte [30] for testing relaxation effect in pipe conveyor contact forces for three belt samples with different construction tested over 24 h with one pipe diameter value, appropriate for each of the belt sample.

The contact forces and belt deflection between the idler stations were also investigated in the test rigs, as described by Pang and Lodewijks in [31]. These test rigs were equipped with a special frame, which could achieve different longitudinal curves and different belt tension. For the same purpose, Hötte et al. [32] accomplished the experimental measurements on the upgraded test rig. The deflection measurements were performed by Staples and Mehta [33] on a test rig similar to [31], which was specially built for an industrial pipe conveyor project with a 90-degree horizontal curve. Another test setup was built, as described by Michalic and Zajac [34] and Molnar et al. [35–37]. This