Simulation of Interaction of a Pipe Conveyor Belt with Moulding Rolls

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Abstract

Interaction of a pipe conveyor belt with moulding rolls is a very interesting problem for producers and also for users of pipe conveyors. There are created high resistances and deformations in this part of pipe conveyor. The determination of contact forces is difficult. The paper deals with problem of computation of contact forces generated by action of a conveyor belt on moulding rolls. Analysed is moulding part of the belt during its transformation from flat to tubular form. Analyses were performed by means of the Finite Element Method.

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1. Introduction

The use of pipe conveyors for transportation of bulk material has gained much popularity over the past decade. The popularity lies in their ability to ensure protection of the environment it passes through, besides their cost-effectiveness, low labour and operating costs demands [1]. They application is especially suitable in chemical and power industry. In operation, the conveyor belt changes its form from flat to tubular shape. As transported material is enclosed by a coiled belt, it is protected from damage during the transport and moreover, environment is protected from contamination. At present, pipe conveyors represent widely used and accepted conveying systems, and are continuously developed for effective transport of bulk materials over long distances [2].

Transformation of belt shape is provided in conveyor transition segment by hexagons of supporting rollers and tipping device that are necessary parts of every pipe belt conveyor [3]. Typical arrangement of transition segment is depicted in Fig. 1 and Fig. 2.

Supporting structure of transition segment is loaded by force, which are acting between the belt and rollers. These forces have to be considered in design and dimensioning structural members.

Simulation of transformation process of pipe conveyor belt and determination forces acting among the belt and rollers represents itself a difficult problem that is practically impossible to solve by analytical methods. Hence the numerical methods have to be utilized.
Schilling et al. [4] applied the finite element method (FEM) for analysis of force distribution in a belt of a pipe conveyor. They analysed a small sample of the belt that was moulded to the pipe form by moulding rolls. Del Coz Díaz et al. dealt with determination of stress and strain and warping effects in a pipe conveyor by the FEM [5]. These authors ([4] and [5]) used general purpose FEM program ABAQUS as simulation tool. The FEM and the same program were used in analyses presented in this paper. Michalik et. al. [11] deals with using of new Computer Integrated System for the automatized measuring of strength in the conveyer belt of pipe conveyor.

![Image of belt transition segment](image1.png)

**Fig. 1.** Beginning of belt transition segment.

![Image of hexagonal moulding idler station](image2.png)

**Fig. 2.** Hexagonal moulding idler station.

2. **Method of analyses**

The process of belt transformation was solved by FEM dynamic analyses. Though in a case of small translation velocity of the belt dynamic effects could be neglected, dynamic analyses were chosen for their better possibilities to solve contact problems. Dynamic analysis can be performed by implicit or explicit method. In the implicit method, the set of algebraic non-linear equations with unknown nodal displacements have to be solved in every time step. The solution is then time demanding and moreover, problems with singularities can appear, typically, if a body is supported by contact constraints only. In explicit integration scheme, no solution of the set of algebraic equations is necessary, and unknown variables at time step \( t + \Delta t \) are computed directly from their values at time \( t \).

Explicit central-difference method of solution was used. The method though primary intended for solution of dynamic problems was more suitable for the solution of contact problems in the case studied [6]. In an implicit dynamic analysis the integration operator matrix must be inverted and a set of non-linear equilibrium equations must be solved at each time increment. The explicit method uses no solution of the equilibrium equations as values at end of a time interval are computed directly from these determined in previous solution steps, hence solution individual time steps is much faster than
in implicit method. Disadvantage of the explicit method is in its conditional stability due to which time increments less than critical value should be used.

Implicit method is integrated with ABAQUS/Standard program; explicit method is implemented in ABAQUS/Explicit program. The ABAQUS/Explicit program used offers fewer element types than ABAQUS/Standard. For example, only first-order, displacement method elements (4-node quadrilaterals, 8-node bricks, etc.) and modified second-order elements are available. When using explicit method, each degree of freedom in the model must have some mass or rotary inertia associated with it. However, the method provided in ABAQUS/Explicit has some important advantages for solution of the problem studied:

a) The analysis cost rises only linearly with problem size, whereas the cost of solving the non-linear equations associated with implicit integration rises more rapidly than linearly with problem size. Therefore, ABAQUS/Explicit is attractive for very large problems.

b) The explicit integration method is more efficient than the implicit integration method for solving extremely discontinuous events or processes.

c) It is possible to solve complicated, very general, three-dimensional contact problems with deformable bodies in ABAQUS/Explicit.

d) Problems involving stress wave propagation can be far more efficient computationally in ABAQUS/Explicit than in ABAQUS/Standard [7, 8, 9].

The object of analyses was conveyor belt of type EP 500/3HP 5+3, which is typically used in many operated pipe conveyors. The width of the belt was 800 mm, length of moulding part was 6 400 mm and spacing among idler stations was 1 000 mm.

The course of the simulations was divided into 3 steps. In the first step, the conveyor belt was gradually shaped to the pipe by the help of moments $M_1$ and $M_2$ distributed over its edges, see Fig. 3. At first, model was gradually loaded by moments $M_1$. The belt was longitudinally divided into two symmetrical parts and nodes in plane of symmetry were fixed by prescribing zero values of all degrees of freedom during this phase. After the moments $M_1$ achieved their final values, the belt was loaded by moments $M_2$. Both moments were proportional to time $t$ and their final values were determined so that at the end of this step the belt was fully coiled. Moulding rolls were fixed during this step.

Fig. 3. Formation of the conveyor belt.

Fig. 4. Prescribed displacement of moulding rolls.
I the second step the moulding rolls were moved to their final position so that they round coiled conveyor belt, as it is show in Fig. 4. In order to maintain packed shape of the belt, distributed moments were kept on their final values during the second step.

In the third step of analysis the coiled belt was gradually released so that occupation of its final shape within the frame of moulding section occurred (Fig. 3). At the same time the nodes in pane of conveyor belt was released from all prescribed degrees of freedom. During this step a loading by gravitational forces oriented in negative direction of the $y$ axis was applied.

Finite element mesh was created of shell elements. Type S4R element used is a general- purpose four-node double curved shell element suitable for a wide range of applications [7]. The element is capable of deformation due to transverse shear stress. In every node are defined three translation and three rotational degrees of freedom. Each of six degrees of freedom uses an independent bilinear interpolation function.

The option general contact for definition of the contacts between the conveyor belt and moulding rolls was used. General contact allows a user to define contact between many or all regions of a model with a single interaction [8]. Within contact definition application the option self-contact was considered as well. Thanks to this function, it was possible to consider the contact that was formed by covering of both edges of the belt during its deformation to the pipe shape. In the computation model two types of contact pairs were used. Moulding rolls and conveyor belt created the first contact pair, and both side zones of conveyor belt were the second contact pair.

Fig. 5. Conveyor belt during unpacking process.

3. Results

The procedure described above enabled deeper insight into problematic of pipe conveyor loading in process of conveying belt transformation. Typical results represented by courses of components of forces in areas of contact among the belt and moulding rolls are plotted in Fig. 6, 7, 8. The graphs represent forces in the first roller guide in which is the conveyor belt already coiled to demanded shape of tube. In operation, this guide is subjected to maximal loading because the belt that is flat at one side is flat is forced to come into coiled form, see Fig. 5. Hence the largest resistive forces acting against belt movement are developed in this guide.
Fig. 6. Components of contact forces in $x$-axis direction.

Fig. 7. Components of contact forces in $x$-axis direction.

Fig. 8. Components of contact forces in $x$-axis direction.
4. Discussion

The process of pipe conveyor design is still mostly performed on the basis of knowledge of and personal experience of design engineers. There is no a unified technical standard including rules for calculations of basic parameters necessary for proper selection of the belt type, choice of drive and dimensioning of load bearing structure. Methodology and procedures from standards for classic belt conveyors based mostly on empirical formulas are often used instead. This procedure has many limitations and negatives. Especially, applications of classic conveyors motion resistance calculations in design of pipe conveyors can lead to underestimation of loads arising from conveying belt transformation and the same holds for calculation of contact loads in idler stations.

The present methodology of pipe conveyors parameters determination is based on different empirical coefficients defined by individual producers during several years. Results calculated by these methods are in many cases different. This fact is reflected in different dimensioning and selection of the conveyor belts, rollers and another parts and different operating costs as well. Many producers and users wise up to these facts and necessity of more detailed research for further development of analytical and simulation methods applicable to solution of pipe conveyors design and operating problems.

The procedure based on FEM presented in this paper gives possibilities for deeper study of interaction of conveyor belt and idler station guidance rolls. Its main use is to analyse variables influencing regularity of formation and determine values of motion resistances and contact forces. The goal is to identify conditions that exercise an influence of motion resistances and contact loads and compose them to the process of pipe conveyor design.

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