Calculation and Simulation Model of a System RopeCon

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Abstract **– Transport of material plays a very important role in the mining. The main task of the material transport is conveying raw materials into the storage bin. There are applied in the area of bulk solid transportation not only the traditional kinds of transport. The unconventional transport systems are usually developed from the "classic" systems. One of the new transport methods is application of the system RopeCon, which represents a combination of the rope transport and belt transport. This paper deals with the creation of geometry and simulation model of the RopeCon conveyor.**

Keywords **– Geometry, Model, RopeCon, Simulation, FEM.**

1. Introduction

The role of transport technologies, which are applied in mining of the minerals and the raw materials, is decisive and substantial. Material transport was realized in the mining industry during a long time period only by means of the mining railway transport, which was combined with the road transport. However, later on there were created new transport technologies and these newly developed transport systems were improved and optimized continuously, whereas this process is lasting till now.

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However, the transport of material in the area of mining is often connected with various problems and complications that have to be solved quickly and efficiently. An efficient solution consists in application of such solving method, which is optimal and suitable for elimination of the given mining problems taking into consideration a maximum number of the operational criteria [1].

Nowadays, the dominant position within the mining transport technologies have the mining railway transport, road transport, rope transport and the belt transport. It is possible to say that the belt conveyor belongs among the most important conveying systems utilized in the mining industry. There are applied within the conveyor belt transport various investigation approaches based on the computer simulation and the analytical methods [2], [3].

The computer simulation is a robust tool determined for the belt transport, which is operating in the mining area. Application of the simulation methods enables us to identify various parameters as well as to obtain the necessary information quickly and reliably during projection of the complex transport systems in relation to the various dynamic components [4], [5]. The calculation models used in the belt transportation, which is installed within the mining operation, can be also focused on the operational indicators, e.g. on the various economical characteristics [6].

In the present, research of the belt transportation systems is oriented to the several problematic areas. The first one is scheduling [7] and prediction specified for mining of the individual raw materials and minerals [8]. Another important area is development of the new transport technologies based on the classic continual conveying systems as well as research of the operational parameters for the existing continuous transportation systems.

A typical example of the innovative transport technology is application of the pipe conveyor. The pipe conveyors are always interesting not only for their users but also for a wide scientific society. The correct solution of the pipe conveyors requires performing of the experimental measurements together with application of the simulation methods.

For example Zheng et al. [9] presented a combined calculation model created on the basis of the DEM and FEM in order to analyse the contact forces that are acting in the conveyor belt. The obtained results were analyzed in detail within the experimental measurements.

Realisation of the experimental measurements during the conveyor belt operation is very demanding, especially in the case of the pipe conveyors. There is applied, for example, special experimental testing equipment [10], [11], which enables obtaining information concerning the motional resistances [12] as well as to evaluate other operational parameters, according to Zamiralová and Lodewijks [13].

There are many obstacles and complications in the mining industry by conveying of raw materials. These are hardly solved by classic transport means and transport systems. For this reason, new modes of transport are still being sought to ensure the smoothest possible course of conveying [14].

RopeCon is a special conveyor for conveying of bulk and fine piece materials [15]. Its main advantage is the ease of obstacles overcoming along the transport route and also high environmental friendliness [16]. The basic characteristic of the RopeCon is its versatile use. Due to the distances, it is a suitable solution for conveying of materials from the distant places to the storages [17]. By conveying for very long distances, it is needed to fetch through, for example developed areas, rivers or routes [18]. These obstacles are easily reducible for this system. This overcoming of obstacles is the main advantage of the system RopeCon.

The system RopeCon is a very prospective form of bulk material transport, which can be used in the mining of the minerals and the raw materials, but it is also necessary to say that development and application of this system requires a systematic research approach. The main research areas should be focused on determination of the operational characteristics, investigation of the motional resistances and loading of the individual constructional segments. Furthermore, it is needed to investigate construction of the supporting parts, especially the steel ropes.

Application of the computer simulation tools is a very suitable methodology taking into consideration the assumed complexity of the experimental measurements. Creation of the proper calculation model is a demanding task. Therefore, this paper describes a possible procedure developed for creation of the calculation model together with the basic information obtained from the performed calculations in a full range.

2. Materials and Methods

2.1. Theory and principles of RopeCon transport system

The continuous system of bulk material transport RopeCon was created as a combination of the belt conveyor and the rope transport. The RopeCon efficiently integrates advantages of both systems in order to transport a large spectrum of raw materials and minerals under the difficult mining conditions. The main advantages of this system are: ability to transport high conveying volumes of the materials on the long distances, possibility to be installed in various terrains, stability and adaptability. Of course, there are also known disadvantages of this system, for example demanding maintenance and necessity of continuous monitoring. In principle, the overall construction of the system RopeCon is founded on the design of the standard belt conveyor.

The system RopeCon is classified among the transport systems equipped with a tensile element. The conveyor belt fulfills both the tensile and the carrying function. Trajectory of the belt is oriented from the head pulley (i.e. the driving pulley) to the tail pulley (the reversing pulley).

The transport system RopeCon (Figure 1.) is driven by an electromotor near the feeding station. In addition to the fact that the motor consumes energy for drive, it also produces electric energy during the braking process of the conveyor. The difference in power consumption and energy production is in some cases negative, this means, that sometimes it is produced a higher amount of energy than it is needed for conveyor drive. The conveyor belt has mounted the half-axis equipped with the wheels along its length in order to realize the movement of the conveyor. These wheels move along steel ropes, which are fixed on the towers. The guiding wheels are keeping the conveyor belt from torsion and tilting thanks to the deep grooves that are created on the wheels for placing of the track ropes. This system does not require any guiding device. A possible damage of the belt edge is eliminated in this way and the durability of the conveyor belt is increased, as well. The conveying trajectory is situated above the level of the terrain.

In addition to the elements, there are supporting frames along the track which realize the required distance among the top and the bottom part, among the empty and full conveyor belt. Other parts are sensors of the belt, which sense unnatural excessive movement of the belt influenced by weather conditions. In the case when the belt is unstable more than normal, the sensors send a signal for conveyor turning-off [19], [20].

Figure 1. Transport system RopeCon [21], [22]

2.2. Elements of the system RopeCon

The conveyor RopeCon is formed by movable and immovable elements. The movable elements include conveyor belt, drive (Figure 2.) and reverse drum, and the immovable elements include motor, ropes, construction and towers. The conveyor belt is the main part of the conveyor, and it has supporting and loading function.

It uses a special type of conveyor belt, which was designed and supplied by the Contitech company. It was developed for the need of RopeCon. The belt has sidewalls that prevent the material from falling. These belts offer quality and long-term solution for conveying bulk materials for long-distances. They are produced with different sizes of the belt width, height of the side-walls and strength. The strength of conveyor belt provides the belt tube, which can be made from polyester-polyamide fabric or steel-cord core. For trouble-free fixation of the semi-axles the conveyor belt was made in some places without steel cords. Corrugated side walls and holders of half-axis are part of all types of belts used on the RopeCon system [20], [23].

The transport system RopeCon contains not only the basic constructional parts, but it also consists of a set of supplementary components that are determined for improvement of the system operation. The most important supplementary component is the sensor of movement. This sensor serves for monitoring of the conveyor motion during the current operational time and in an emergency case it switches the whole transport system off. Additional equipment is the cover shelter, which protects the transported material against the weather impacts. The last type of the possible supplementary equipment is installation of the service footbridges, which are necessary during the maintenance process of the whole transport equipment.

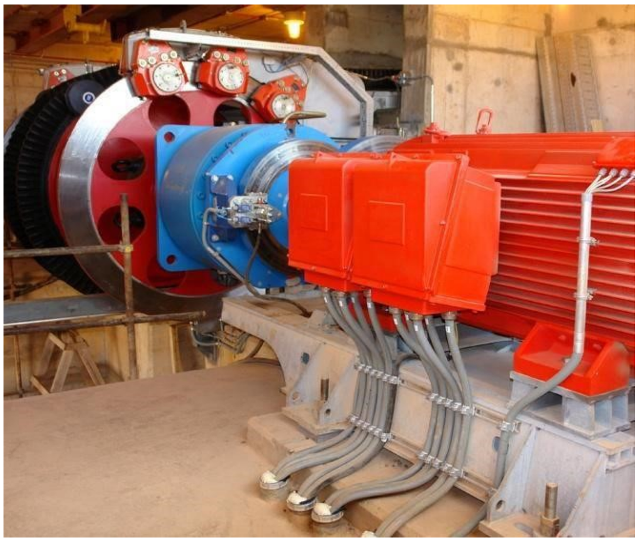

Figure 2. Driving station of RopeCon [20, 24]

The drive system of the RopeCon consists of an electric motor, gearbox, drive and reverse drum (Figure 2.). RopeCon is equipped with two independent mechanical braking systems and all its braking actions are regulated with the aim to ensure a constant deceleration and regulated stop in all situations. This regulated brake uses the principle of braking energy recovery.

The maximal incline of the transport system RopeCon trajectory is up to 35° and the highest speed of the conveyor belt is 12 $m.s^{-1}$. Important is also the fact that the RopeCon is environmentally friendly technical equipment.

3. Creation of model of the system RopeCon

For creation of the geometry of the model, the program PTC Creo Parametric 3.0 M070 was used. On the basis of documents that are freely available from the company Doppelmayr, (Table 1.) a computational model of the RopeCon was created, which is the most similar to reality (Figure 3.). The sizes of some constructional parts of the belt conveyor were determined by estimate, because their exact sizes are not publicly available. The main parts of the conveyor, such as the conveyor belt and the corrugated side, were determined on the basis of exact determination.

Table 1. Main characteristics of the calculation model [24]

Transported material	Landeck silica, phyllite	Belt width	800 mm
Bulk density	1660 $kg.m^{-3}$	Useful width	630 mm
Lump size of material	0-1000 mm	Height of side-walls	200 mm
Material size after crushing	0-250 mm	Belt type	EP 1250/4-7T/3T
Rope weight	39 $kg.m^{-1}$	Track rope	4 x 42 mm
Weight of supporting construction	56 $kg.m^{-1}$	Rope type	WS 1670 $N.mm^{-1}$
Distance between drums	248.9 m	Basic tension	4 x 475 kN

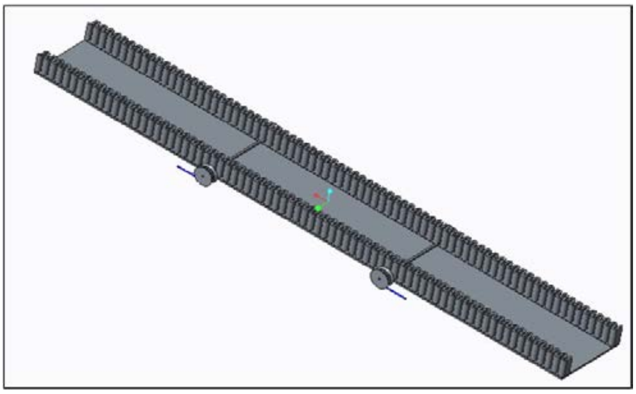

Figure 3. Geometric model of the system RopeCon

3.1. Boundary condition

Boundary conditions define the behaviour of individual parts. By the boundary conditions we allow or we prevent the movement, or movement of parts (Figure 4., Figure 5.). Determination of movement is by the axes X, Y, Z. In addition to limiting the movement of the individual parts, the boundary conditions also ensure that the model sticks together and by calculation it does not fall, but it has its positions. By determination of the boundary conditions of the created model, the boundary conditions for all its parts were not defined. These, which are in contact with the other parts, are affected by each other. Therefore, it is sufficient to define only conditions for this part, which is supporting. Interaction among these parts is defined by other function, which provides limiting of other undefined parts. The conveyor belt is the main part of the computational model. The behaviour of the conveyor belt affects all parts of the model. The conveyor belt consists of two parts. The shorter part of the conveyor belt is free at one end. The second edge has a mounted clutch, which connects the two conveyor belts together. The boundary conditions were applied on the free end so that this edge had prevented movement in all directions, i.e. in the direction of the axis X, Y, and Z. The second part of the conveyor belt is as the first part, on the one side free and the other side attached to the clutch which connects this with the shorter part of the conveyor belt. The free part of the conveyor belt has prevented movement in the direction of the axis Y and Z. In the direction of the axis X a movement about 50 mm is defined. This movement realizes the tension of the conveyor belt.

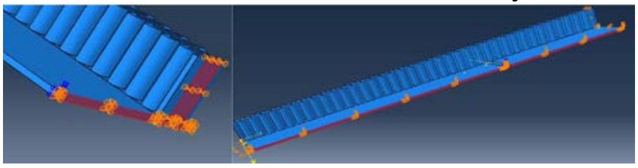

Figure 4. Application of the boundary conditions to the conveyor belt and side

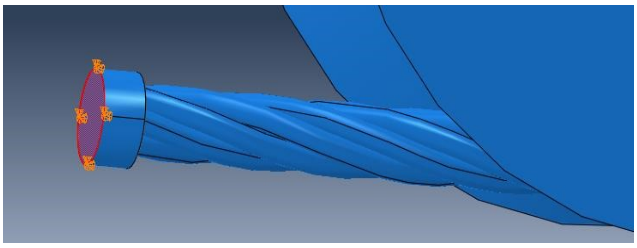

Figure 5. Application of the boundary conditions to the steel rope

Steel rope consists of wires and insert. The used rope is at both ends ended by roller endings. At this endings were applied the boundary conditions that affect the rope behaviour. At the one end, the movement was blocked in all directions and at the other edge there was free movement only in the direction of the axis X. In the direction of the axis X, the tension of the rope is realized by another function.

The corrugated side is vulcanised to the conveyor belt and it is defined separately in the model. The side is not compartmented, as this is at the bottom of the conveyor belt, but it is created as a whole. At the end part, where the conveyor belt is fixed against the movement in all directions, the movement is also prevented in the direction of the axis X and Y. The opposite end of the side has not defined the boundary conditions, because this end defines the tension for the conveyor belt. The conveyor belt also corrects the direction of the side.

The used model is a quarter of the created model; therefore it is necessary to define the boundary condition so that the model behaves as a whole during the calculation. By the help of the boundary conditions UR1, UR2 a UR3 the mirroring is defined and this gives the model the properties necessary for behaviour as a whole. Along the part marked in the figure we define the boundary conditions, namely: in the direction of the axis X, the movement of the model is inhibited, in the direction of the axis X and Z by the help of the functions UR1 and UR3, the model is mirrored.

3.2. Meshing of finite elements

The meshing of finite elements was generated from the elements of the type Solid. Parts of the models are divided by applied network. Each element was created separately. Elements are Hex-formed, so they have hexagonal form. By meshing of the parts, which create the conveyor belt, the same size of the meshing was not used with regard to the whole part. These parts come in contact with corrugated side on the edge, which has a different size of meshing than the conveyor belt. In order to achieve more accurate results of the impact of the side to the conveyor belt, the size of the meshing was aligned. The other parts of the model were created with the same large parts (Figure 6.).

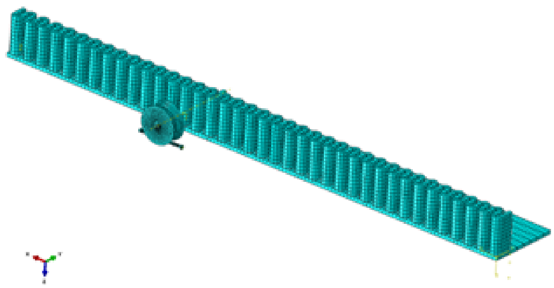

Figure 6. Example of meshing

3.3. Materials' characteristics

There are summarized in Table 2. the most important material characteristics of the individual constructional parts installed in the given transport system. These material characteristics were used in the calculation model.

Loading of the conveyor belt, which is caused by the transported material, is included in the calculation process because the conveyor belt loading significantly influences the stress-deformation status of the whole transport equipment (Table 3.)

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Table 2. Basic material characteristics of the calculation model

	Young's modulus of elasticity [MPa]	Poisson's ratio [-]	Density [t.mm-3]
Wire rope	204 000	0.25	$7.85.10^{-9}$
Conveyor belt	60 000	0.35	$3.58.\ 10^{-9}$
Side-wall	397	0.49	$1.099.\ 10^{-9}$
Wheel	2 300	0.39	$1.15.\ 10^{-9}$
Reinforcement	204 000	0.25	$7.85.10^{-9}$
Shaft	204 000	0.25	$7.85.10^{-9}$

Table 3. Basic material characteristics of the transported material

	Phyllite	Sand	Coal
Bulk density	2750 $kg.m^{-3}$	1750 $kg.m^{-3}$	1250 $kg.m^{-3}$

The mineral phyllite was chosen as the main kind of the transported material, which is determined for assembly of the model as well as for the calculations. The phyllite is a metamorphic rock. It usually contains such minerals as silica, chlorites and dark mica.

3.4. Defining of contact pairs and bonds

A special function "Tie" was applied during creation of the simulation model. This function is determined for connecting of the individual components each other. It is necessary to define the "Master surface" for generating of the bonds. The "Master surface" is such a surface, which is superordinate to the "Slave surface". In the case of the static contacts among the individual components, the behaviour of the contact components is defined by means of the function "Constraint".

The function "Interactions" was applied in order to define the contact pairs. This function determines behaviour of the interacting components in the case of the dynamic interactions. The interactions among the wires in the rope as well as between the rope and the wheel surface are the main interactions, which are analysed in the simulation model. The function "Contact control" was applied for stabilisation of these contacts in order to keep the contact as a whole. The contact type "Surface to surface" was chosen for a contact among the wires and the wheel. The contact type "General contact" was used for a contact among the rope wires and the rope core (Figure 7.).

4. Results and discussion

The presented calculation-simulation model was utilised for realisation of several simulation experiments in order to investigate the behaviour of the complex transport system during conveying of three different materials, above all the phyllite (Figure 8.). The loading of the individual constructional parts was monitored and evaluated, namely the conveyor belt, the steel ropes and the guiding wheels.

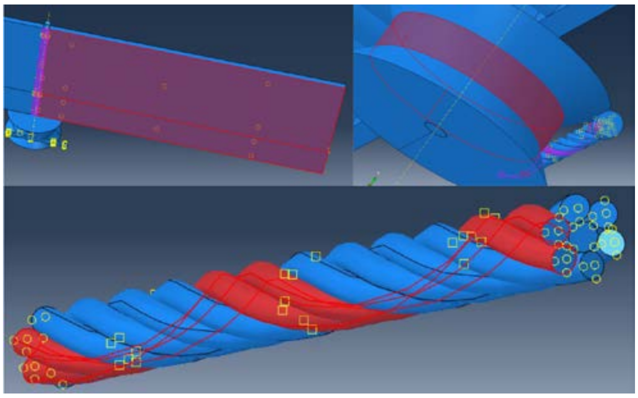

Figure 7. Example illustrating definition of the contact pairs and bonds

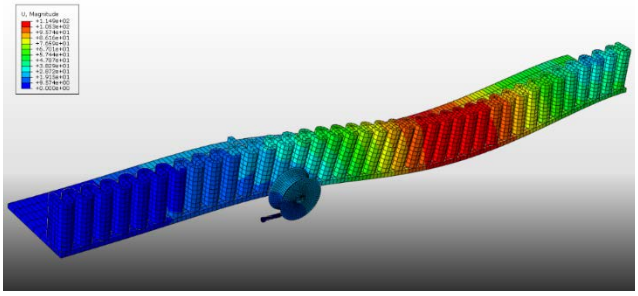

Figure 8. Result obtained from calculation of the conveyor belt deformation during transport of the phyllite

It is possible to realize a wide range of calculations and analyses by the presented calculation model. As an example we can present graphs in the Figure 8., Figure 9., Figure 10. and Figure 11., which show the tension along the conveyor belt. Graphs in Figure 9. and in Figure 10. present tension, which is located along the belt on the model created in this paper. The tension under the side has a different course as a tension in the middle of the belt. This distance is caused by the effect of side on the conveyor belt. The tension in the middle of the belt has a maximum in the point 1595 of the belt length and its value is 1028.57 MPa. The tension under the side has a maximum in the point 2005 and its value is 1107.66 MPa.

The above-mentioned information offers very important data concerning loading of the conveyor belt during the transport of the phyllite. All the analysed stress-deformation statuses confirm a fact that the conveyor belt is dimensioned suitably. Although there is occurrence of an overhang of the belt between the individual pairs of the reinforcements, which are serving for fitting of the supporting wheels, the value of this overhang (0 ÷ 109.3 mm) does not have a negative impact on the operational characteristics (Figure 11.). The overhang value is acceptable in comparison with the classic belt conveyor.

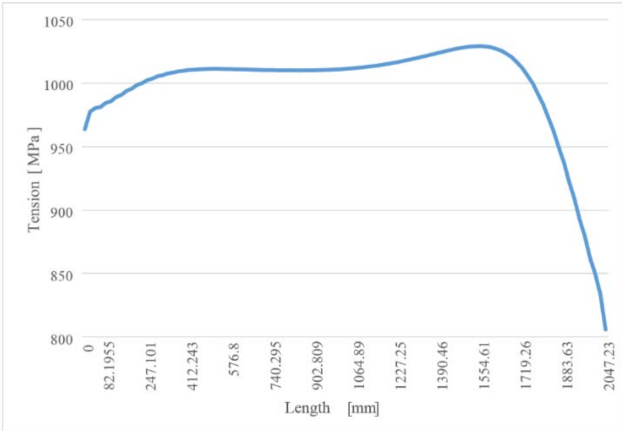

Figure 9. Graph of tension along the conveyor belt (middle of conveyor belt)

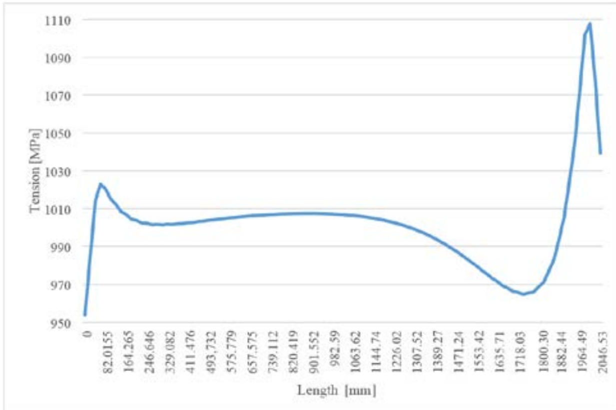

Figure 10. Graph of tension along the conveyor belt (under side)

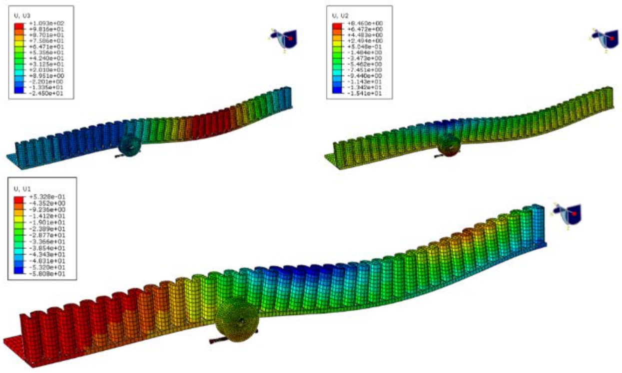

Figure 11. Course of deformation by the conveyor belt

On the other hand, it is necessary to emphasize a fact that such value of the belt overhang would not be acceptable in the case of the classic belt conveyor because such overhang of the belt causes a significant increase of the motional resistances together with a more intensive wearing of the conveyor belt due to the rolling of the belt. However, the supporting wheels, which are fixed to the reinforcements in the RopeCon conveyor, eliminate such unfavourable situation; but in any case it is useful to verify the loading of the steel rope. Deformation of the steel rope due to own weight and weight of the transported material is illustrated in Figure 12.

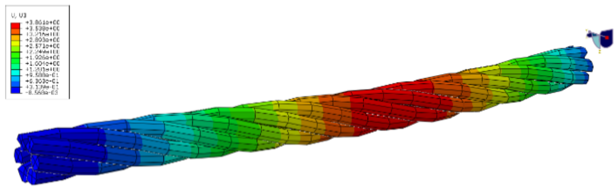

Figure 12. Deformation of the track rope of the system RopeCon

It is evident from the results of the performed deformation analysis that deformation of the track steel rope is not excessive and therefore this kind of deformation is not relevant with regard to the operation of the whole transport system. The given steel rope reliably fulfils the function of a stable support during conveying of the phyllite or other materials without a damage or spillage of the bulk solid along the transport trajectory.

5. Conclusion

The calculation model was created with the aim to create more real analysis of the conveyor RopeCon and to realize a basic simulation of loading, which is caused by the transported material The created model is very similar to the real one, but there is still area for its improvement, for example the geometric shapes and dimensions of the model, or the properties of the model. We have to emphasize that the area of conveyor model behaviour creates an area for its improving.

The presented results offer relevant primary information, which can be used within the first phase of a technical proposal and operation of the analysed transport system. The next research and application of the given computational-simulation model requires to analyse especially the dynamic aspect of this transport system. It will be necessary to perform the following calculations using an explicit method in order to obtain more detailed information about the dynamic operational characteristics as well as the informative values of the motional resistances.

The paper objectively presented the conveyor RopeCon and creation of its model. The created model provides very good background for the next research of the conveyor RopeCon.

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