Research Article

Nikoleta Mikušová*, Ondrej Stopka, Mária Stopková, and Erika Opettová

Use of simulation by modelling of conveyor belt contact forces

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Abstract: Intelligent conveyors include a large number of sensors and also signalling devices. So-called digital twin presents an advantage that creates a virtual image of a real conveyor. Simulation of the conveyor by simulation language can be an example of a tool of a conveyor virtual image. Simulation allows to test the proposed changes and in the case of functionality, to use the changes in the real operation of pipe conveyor. The paper presents the description of the simulated regression model of conveyor and realized simulation experiments within the regression model of pipe conveyor.

Keywords: simulation, conveyor belt, model

1 Introduction

A computer simulation is an essential tool in understanding the dynamics of enterprise systems, especially in recent years. Successful companies already use simulation as a tool for operational and strategic management [1]. The modern simulation paradigm links the model of simulation by integration with a static database of enterprise variables, user-friendly and additional decision support tools [2]. These tools include expert systems or support systems. The development of simulation moved from analytical and optimized models to the integration of simulation models to the tools of decision making. The tools of decision making can then be reused [3]. Integration of models

allows an organization to create a distributed simulation system so that it can simulate a production process. It also provides an overview of the model organization [4].

Belt conveying is one of the most important systems within intra-plant transport systems and a wide range of industries. Continuous realized research, which is focused on various types of problem areas, is necessary for reliable operation of the system. In the field of research, the priorities are an issue related to automation of processes, predictive maintenance, effective operation. Realization of monitoring for the transport process is one of the basic conditions for a reliable implementation. It is possible to realize it in the form of online monitoring, which is more comfortable than the classical approach of realization. Online monitoring also allows to monitor the transported material on the conveyor belt and also continuously monitor the size of the transported material particles and at the same time to obtain huge amounts of data [5]. This way is highly effective in terms of further development of belt conveyor technology used to transport various types of materials. The obtained data can be further used within the maintenance of belt conveyors, the realization of various decision-making processes. Monitoring of belt transport operation is a trend which indicates the direction of the further development of the belt conveying.

Several methods are used for determination of the selected parameters of pipe conveyor and also several models are created. For example regression models, FEM, calculation models, as it is mentioned by authors in [6–8]. One of an interesting parameter of pipe conveyor is presented by contact force. Measurement of contact forces is realized by identification of individual forces developed by the action of the conveyor belt on the individual guide rollers. The guide rollers are located in bushes in a hexagonal shape.

2 Methods of research

The research was realized by the philosophy of regression models. Regression models are created on the base of the relation of variables. The relation is created by the

*Corresponding Author: **Nikoleta Mikušová:** Technical University of Kosice, Faculty BERG, Institute of Logistics and Transport, Park Komenského 9, 040 01 Kosice, Slovakia;
Email: nikoleta.mikusova@tuke.sk

Ondrej Stopka, Mária Stopková: Institute of Technology and Business in České Budějovice, Faculty of Technology, Department of Transport and Logistics, Okružní 517/10, 370 01 České Budějovice, Czech Republic

Erika Opettová: Technical University of Kosice, Faculty BERG, Institute of Logistics and Transport, Park Komenského 9, 040 01 Kosice, Slovakia

Table 1: Tension forces [?]

Tension force (TF)	TF1	TF2	TF3	TF4	TF5
Minimum	3707,86	9322,74	15499,84	20883,43	27320,11
Maximum	3991,66	9761,39	16067,95	21481,35	28037,43

explained variable “y” and declaratory independent variable “x”. The variable “y” presents the normal compressive force and independent variable “x” presents tension force. They can be also described using a simple regression model in polynomial form. In addition to variables, the regression model contains also parameters for capture, coefficients, random component of the regression model, and also polynomial degree [9]. The point estimate of the regression model is a regression function, which is given in the form of an equation. The coefficients of the individual parameters are estimated using the least-squares method. In these models, point estimates are used to verify the statistical significance of the model. The test of statistical significance is referred to as the F-test [10]. If the resulting value “p” is lower than the predicted value in all models, then it can be assumed that for this reason, the regression model is statistically significant. Statistical significance in the regression model is also verified using a statistical test for the parameter of regression [10].

3 Simulation of contact forces of pipe conveyor

The exponential equation (mentioned in the previous part of the paper) was used by the creation of simulation of contact forces of pipe conveyor. In each block of the simulation, an exponential equation was used as a basis for the creation of graphs of the resultant simulation. Values of tension forces are unthinkable part of the simulation with an exponential function. For the tension forces used in the simulation, the maximum and minimum value of the tension force must be entered. Values of the tension forces present the applied force of rollers on the conveyor belt which passes through the roller stand. The tension forces on the individual rollers have not the same values, but each roller has its maximum and minimum value of the force acting on the conveyor belt. Each tension force (minimum or maximum), is measured in the simulation using the exponential function specified in each block of the model. Creation of simulation model applied suitable blocks of simulation, for example, generator of a random number, block for equations, blocks indicating the constant, block

with mathematical function and block for the resultant graphical presentation.

The measurement was realized for identification of the individual forces caused by the effect of the conveyor belt on the guide rollers located in the bush. Significant parameters by measurement of the researched conveyor are the diameter of the pipe conveyor, the width of the belt, length of the belt sample, time of belt packing, the distance among bushes, average temperature, transported material.

4 Simulation model

Creation of the simulation model used regression models as a tools of obtaining of the resultant data. In the simulation, the equations of the regression models were entered, by means of which the input data were evaluated, i.e. maximum and minimum tension forces created by the contact with the guide rollers. The simulation of the regression models includes these equations [9]:

$$Y = 3,0072 + 0,0237x - 2,44E - 07x^2 \quad (1)$$

$$Y = 5,8710 + 0,0082x \quad (2)$$

$$Y = 19,796 + 0,0256x - 2,80 - 07x^2 \quad (3)$$

$$Y = -8,4309 + 0,0625x - 1,46E - 06x^2 \quad (4)$$

$$Y = 101,338 + 0,0484x - 9,19E - 07x^2 \quad (5)$$

Minimum and maximum values of tension forces are presented by the Table 1.

4.1 Model of contact forces simulation

The simulation model was designed in the program ExtendSim8. The model of the simulation consists of individual blocks with instruction commands or values for the evaluation of the simulation. Figure 1 presents the model of simulation.

Figure 1: The model of simulation by the program ExtendSim8

The model is divided into three parts. The first part of the model is created by blocks for input and output of information generated in the other parts of the model. The second part of the model is created by the blocks with entered tension forces of rollers in the idler station of the pipe conveyor. Each of the rollers consists of the blocks “Random Number” and “Equation” with entered maximum and minimum value of the tension force. Table 1 presents the values of maximum and minimum tension forces of simulation.

The next part of the simulation model is presented by the blocks including the equation of the regression model through which input values of the tension forces are evaluated into the final form of the graph. By simulation of all presented equations, the same tension forces were used (Table 1). The result of all simulations are graphs that can be compared and at the same time, it is possible to compare the development of the curve of graphs depending on the entered simulation equation. The simulations created within the obtaining of the results of the simulated regression models are used for the other simulation experiments.

5 Simulation experiments

The simulated regression models (previous chapter of the paper) were used for the simulation experiments. The basis of the simulation consists of a simulation of the previously simulated equations with the indicated tension forces. In simulation experiments, the tension forces will be changed and the result of the experiments will be also graphs showing the course of the curve after changing the tension forces in the simulated models. Experiments are designed with the aim to create a simulation of a digital twin with the possibility of applying the simulated model to the model of real operation. In simulation experiments, an additional block was added to the block “Random Number” in the simulation of guide rollers. This block can change the values of tension forces. It is the block from the library “Utilities”, namely the block “Slider”. The scheme of the simulated model has a modified visual form after adding these blocks. Figure 2 presents the scheme of simulation with the block “Slider”. The connection of the block

Figure 2: Scheme of simulation with the block “Slider”

“Random Number” and block “Slider” is presented as a link to “Con1In” and “Con2In” in this scheme.

The block “Slider” allows to freely change the input values of the tensioning forces. However, the minimum and maximum values are entered as in the block “Random Number”, but the block “Slider” allows to change the input values for the simulated equation by sliding the connector.

5.1 Simulation as an image of a real device

In the created model of the simulation the input values of the tensioning forces were changed several times for comparison of final results. By experimenting in a simulation, in addition to the values of the tension forces, the simulation time can also be changed to determine the result of the simulation at certain time intervals. In the resulting graphs, the curve shows the sequence of the conveyor work, in a shorter time interval or in the longer interval.

5.2 Change of simulated values of tension forces

By experimenting with the created model, one of the changes is the setting of optional tension forces that are changed by the block “Slider”. By changing the tension forces, it is not necessary for the block “Slider” to change the value in each block, it is sufficient the change even one value of tension force. The resultant values can be later compared and subsequently evaluated which of the changes of tension forces of conveyor is optimal for use in real operation of the conveyor. In the first case of changes testing, the original maximum and minimum tension forces in the block “Slider” were equal. The resultant graphs of the simulated models are presented by Figure 3.

5.3 Change of maximum and minimum tension forces

The second change in the simulation was the change of maximum and minimum values of tension forces. A more significant change is by the change of maximum and minimum tension forces. As in the previous cases, the result is

Figure 3: Resultant graphs of simulation after the change of values of tension forces

Figure 4: Graph after changes of maximum and minimum tension forces

a graph, and the curve of this graph shows the progress of the simulation. Figure 4 presents the final graph with the significant change of the simulation course.

The graphs (Figure 4) have a significantly different visual course than the original graphs or graphs after changing the tension forces which are in the range of the originally specified minimum and maximum tension forces.

5.4 Change of simulation time

The change includes two changes, namely in the block “Create” and in the simulation settings, “Simulation Setup”. The total time of simulation was changed from the original 751 finite time units to 1101 and in the block “Create”, from 50-time units to 100-time units. The final graph is presented in Figure 5. The curve breaks and proceeds to the next values 100, 200 until the simulation score the final time. In this case, the simulation ends at the time of 1101.

Figure 5: Graph of simulation after changes in time units of simulation

6 Result of simulation experiments

The result of various simulation experiments is to create a virtual image that is identical to the real model of the device. It is created a “digital twin” of the pipe conveyor device. This allows the application of possible proposed changes not only in the virtual device but also in the operation of the real device of the conveyor. The virtual image of the conveyor is not only an excellent tool for testing of the proposed changes but also for the visibility of the results and it creates an image of the device’s behaviour before and after the proposed change. Application of the proposed changes is due to the digital twin of the device much simpler and more efficient. The device in real operation behaves like a simulated virtual device.

7 Conclusion

Simulation of regression models is based on the evaluation of input data by equations. These can be linear equations and also exponential equations. The model of simulation presented by this paper was created from several equations of regression models. Each of the equations was associated with the specific guide roller in the idler station of the conveyor. Each of the simulated models was individually evaluated and then compared with the other results. Each of the guide rollers had specified values of maximum and minimum tension forces. By simulation experiments, it was monitored the evaluation of simulations on the base of realized changes. These were a number of proposed changes, which were subsequently evaluated. Particularly, minor or significant changes were evaluated. The change of input data of tension forces did not cause major changes, in the case of values within the range of specified

maximum and minimum contact forces. Visible changes in the resultant graphs were possible to monitor after the change of maximum and minimum tension forces, but also after the change of time units of the simulation. Each of the simulated models can be used as a virtual image or digital twin of the real device of pipe conveyor. The simulated changes can be applied in the real device.

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