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The experimental research of the conveyor belts damage used in mining industry

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The conveyor belts represent the most productive, and thus even the most economical transport device with a high transport performance and ecologic harmlessness. From the point of belt conveyor operation, the most important construction element is the conveyor belt. During the operation, the conveyor belt is influenced by many different stresses, which cause the process of damaging and wearing the belt. In order to describe the processes related to the conveyor belt wear due to material's impact, it is necessary to analyse the impact loading process depending on the time during which the impact processes are spreading. The objective of the article is to identify the effect of selected parameters on the impact force while applying the Design of Experiment method. The result of the design of experiment shows a significant effect of the drop height, drop hammer weight, and the interaction between them on the impact force. We receipted that the drop hammer head type in the considered conditions has not significantly effect on the impact force. Using mathematic models, the relationship between the impact force local peaks and various values of the impact process input parameters (drop hammer weight and drop height) is identified. For the first impact force local peaks it has been confirmed by already existing multiple linear regression model. Other local peaks of the impact force are affected by the damped motion of an object falling onto the conveyor belt. As a result, for the other local peaks were formed the different, simpler forms of the regression models. The experimental measurements have been performed on a test rig, which was developed at the Institute of Logistics FBERG of Kosice.

Key words: *8 rubber-textile conveyor belt, impact force, design of experiment, regression models.*

Introduction

Belt conveyor is a commonly used equipment of continuous transport; it has a high efficiency and large conveying capacity, simpler construction, small amount of maintenance (Marasova, 2006). Can be achieved at different distances, different materials transportation (Lihua, 2011). Belt conveyor is widely used in mine, coal, chemical industry, ports, and power plants (Cun et al., 2012).

Despodov (2002) proposes the complex analysis of possible solution that is necessary in order to select an optimal transportation system. Beside the minimal specific costs, the analysis includes capital investment costs, manpower requirements, safety, underground atmosphere pollution, reliability and automation possibilities of the system. The economy of a mining company operation is significantly influenced by the costs of raw material transportation. Therefore, it is crucial to select a proper transportation technology (Lukac, 2002). Requirements demanded by production plants regarding minerals are currently rising, which results in the increasing traffic intensity of material flows in mining companies. Transportation solution is offered by the continuous belt conveyor system (Drottboom, 2013).

A conveyor belt is the most important and, at the same time, the weakest link of the belt conveyor system. Conveyor belt damage is a frequent cause of unplanned downtime, particularly when the belt conveyor system serves as the main mining transportation. Partial or full damage of conveyor belt occurs as a result of several factors. Analysis of negative factors within the coal transportation and possibilities of reducing the impact thereof, especially on the environment, are dealt with by the authors (Grujic et al., 2011), (Boroska et al., 2007). The damage primarily occurs to the upper cover layer of the conveyor belt and later on to the carcass and the lower cover layer of the conveyor belt (Fedorko et al., 2014). Mazurkiewicz (2008) also dealt with the problem of conveyor belts damages. Cerny (2010) describes in his paper how important the wearing process is for rubber products under intensive loads, such as conveyor belts for the transportation of rocks. Sharp edges and surface roughness gradually cause that rubber parts wear out. This wear significantly damages individual parts of the product and destroys it. Wear and fault detection of conveyor belts deal the authors (Xie et al., 2015), (Chen et al., 2015).

In addition to the wear, insufficient strength of the conveyor belt is another negative factor. In case the conveyor belt strength is undersized, disruption occurs, as well as consequent down time due to repair or replacement. Conveyor belt disruption represents an unacceptable risk to the conveyor belt system operation (Tomaskova and Marasova, 2012). It is very important to study dynamic properties, improve efficiency and productivity, guarantee conveyor safe, reliable and stable running (He and Li, 2011).

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Identification of the effects of the selected factors on the strength of rubber-fabric conveyor belts and their interactions, while applying the DOE method, was dealt with by the authors (Ambrisko et al., 2016).

Requirements regarding the conveyor belts depend on the method of use thereof; therefore, entire conveyor belt and its individual components are subjected to testing. Required conveyor belt properties are identified by the testing prescribed in standards, technical or technological regulations.

Taraba (2004) presents the methods used in Slovakia to test the properties of conveyor belts. The methods of basic characteristics testing conveyor belt with a textile carcass and rubber cover are dimensional, functional, physical, physical characteristics of covers and fire-technical characteristics. The problem of an engineering constructions design for effects of fire results from contemporary knowledge and procedures used in technical practice, however, is not limited only to norm recommendations but also looks for other suitable methods of design (Kucera and Pokorny, 2011).

Conveyor belt tests carried out within the experimental research and the results presented in this article can be classified as the group 1 tests, according to the paper (Hardygora, 2002). Results of experimental measurements of conveyor belt quality are presented in the paper (Zamiralova and Lodewijks, 2015). Hou and Meng (2008) described experiments designed in order to establish the dynamic properties of the conveyor belt material.

The conveyor belt damage process may also be solved while applying the modelling research methods. The use of modelling within the raw material transportation process is described in the paper (Saderova and Bindzar, 2014). The reliability of raw material transportation using the conveyor belt system with the minimum operating costs is presented in the papers (Ambrisko et al., 2015), (Bugaric et al., 2012), (Bugaric et al., 2014). Mazurkiewicz (2015) describes in his paper the maintenance of belt conveyors with using fuzzy logic. Dynamic loads produced by falling sharp-edged lumps of the material handled result in punctures, slits of the belt cover and damage to the cables (Hardygora and Golosinska, 1986).

The process of dynamic impact stress of conveyor belts is discussed in papers (Fedorko et al., 2014), (Grincova et al., 2009) which monitor the impact force magnitude at the first local peak. The article presents the results of the laboratory research of other local impact force peaks with the aim to identify the interaction between the weight of the falling object and the drop height at the impact site.

Material and methods

The entire experiment was carried out using the testing equipment, depicted in Fig. 1, facilitating the simulation of the material's fall onto the conveyor belt, with or without the support system. These experiments were carried out without the support system. During the experiment, specimens from the P 630/3-type conveyor belt were collected. Test objects with the sizes of 1400 x 400 mm were cut out of the conveyor belt specimens. The test specimen preparation method is described in the paper (Fedorko et al., 2014). A test object was fixed at both ends in hydraulically operated clamps. Another hydraulic device was used to stretch it, applying the force equal to 1/10 of the belt strength specified by the manufacturer. A drop hammer of the respective weight was elevated up to the required height using the tackle and dropped in a free fall onto the test specimen.

Fig. 1. Measuring Equipment Scheme (Photo Authors).

Experiment preparation and subsequent evaluation were carried out applying the DOE method. *The Design of Experiments* (DOE) method facilitates obtaining the knowledge and achieving the improvement of technological and laboratory processes. This method represents a sequence of pre-designed experiments during which the input variables (factors) are deliberately modified; subsequently, corresponding changes of the output variable, the so-called response, are identified. One of the objectives of our article is to identify which of the factors, or interactions thereof, entering the process are decisive for the monitored response and thus find an optimal setting of the key input factors.

There are several methods how to prepare the design of the experiment performance. In our case, we chose the full factorial design with three factors, acquiring two levels. The levels are usually designated as the low level and the high level, designated in an abbreviated (coded) form with the +1 (or "+") and -1 (or "-") symbols.

Experiment designing and execution is followed by the identification of the effects of individual factors on the response. A factor's effect is defined as the response change caused by the factor's level change. If any of the main factors is examined, we speak about the factor's main effect. The main effect of factors may be calculated applying several methods. In the case of the full two-level factor experiment, the effect of an F factor may be estimated as the difference between the effect at the "+" level and the "-" level, i.e. as the difference between the average response values at the factor's high level and low level (Montgomery, 2002). It applies that

$$E_f(F) = \bar{y}_{F+} - \bar{y}_{F-}, \tag{1}$$

where $\bar{y}_{F+}$ is the average response at the high-level setting of an F factor and $\bar{y}_{F-}$ is the average response at the low-level setting of a factor.

The relationship between the variable y and several independent variables x_j, $j = 1, 2, \cdots, k$ may be expressed by the multiple linear regression model in the form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \ldots \beta_k x_k + \varepsilon, \tag{2}$$

where β_0 and β_k for $j = 1, 2, \cdots, k$ are regression model parameters and ε is a random error.

The regression model parameters are estimated using the method of least squares. To verify the statistical significance of the regression model, we use the F-test of statistical significance of the model. The statistical significance of the regression model parameters will be verified by testing the statistical significance of regression parameters.

Result and discussion

Monitoring of the effect of selected factors on the impact force.

At the designing commencement, the experiment's objective was determined, as well as the input factors and the monitored process outputs. Within the prepared experiment we monitor the effect of three factors on the magnitude of the impact force F_I (response): weight of the falling load (A factor), drop hammer's drop height (B factor), drop hammer head type (C factor). Input factors and their levels are listed in Table 1.

Tab. 1. Input Factors and Their Levels of Experiment with Three Factors.

Level designation	**Drop hammer weight [kg]**	**Drop hammer's drop height [m]**	**Drop hammer head type**
	A	**B**	**C**
Low (-)	50	0.6	Sphere
High (+)	80	2.2	Pyramid

The minimum weight of the falling drop hammer was determined to 50 kg and the maximum weight to 80 kg. The minimum drop height of the drop hammer was selected at the level of 0.6 m; the maximum height was 2.2 m. The maximum height was determined upon the experience as the height at which no serious damage is still caused to the conveyor belt. The material's impact was simulated using two types of impactors: a pyramid and a sphere (Fig. 2) without the support system.

Fig. 2. Two types of impactors (Photo Authors).

The objective of the experiment was to determine which of the considered factors, or the interactions thereof, have a significant effect on the maximum magnitude of the impact force F_I [kN] developed at the fall of the load (drop hammer) onto the P630/3 conveyor belt. The resulting response values in individual experiment steps are depicted using a cube in Figure 3. The cube corners contain response values in individual experiments.

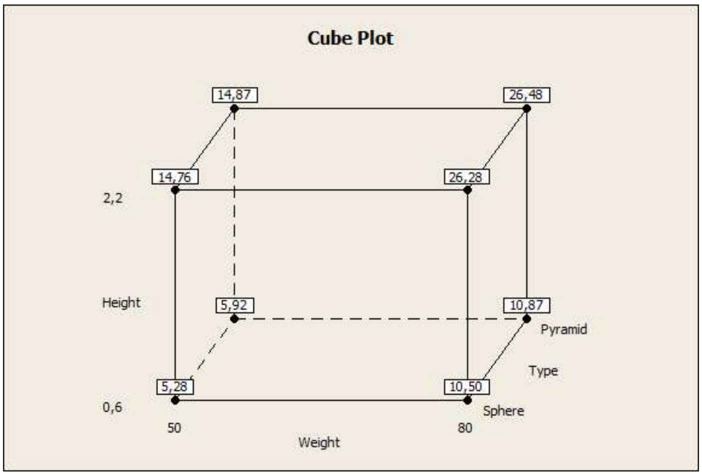

Fig. 3. Graphical Representation of Response Values in the Experiment (Minitab Output).

The effect of all main factors (A, B, C) and the second-order interactions (AB, AC, BC) are in Table 2. The significance of the individual effects of factors, or their interactions, is tested applying the t-test and by the p-value determination. It applies that the effect of factors, or interactions, is not statistically significant if the p-value increases in more than 0.05. The analysis indicates that two main factors A, B and the AB interaction have a statistically significant effect on the response, i.e. on the output value of the impact force.

Tab. 2. Effect of Main Factors and Second-Order Interactions.

Parameter	**Effect**	**Coefficient**	**t-test**	**p-value**
Constant		14.370	319.33	0.002
A	8.325	4.162	92.50	0.007*
B	12.455	6.227	138.39	0.005*
C	0.330	0.165	3.67	0.170
AB	3.24	1.620	36.00	0.018*
AC	-0.045	-0.022	-0.50	0.705
BC	-0.175	-0.087	-1.94	0.302

Evaluation of the effects of individual factors and their interactions was carried out also applying the Normal Probability Plot (Fig. 4). For this plot, it applies that all factors and interactions located out of the drawn line are regarded as statistically significant. The plot indicates the fact that is already known, particularly that the response is significantly influenced by the drop hammer weight (A factor), drop hammer's drop height (B factor), and a mutual interaction of the first two factors.

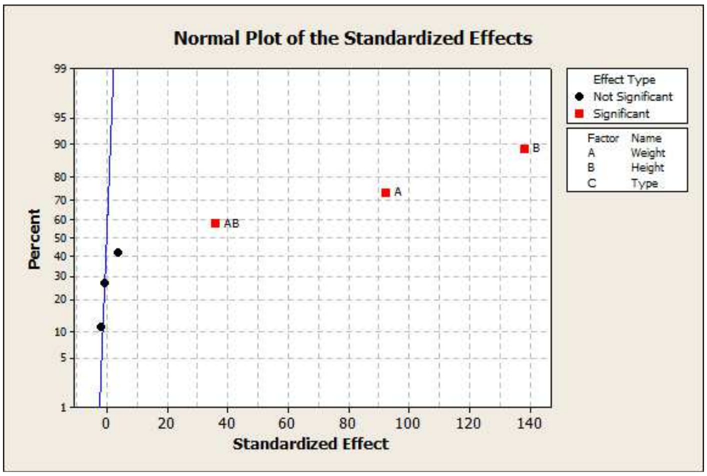

Fig. 4. Normal Probability Plot (Minitab Output).

Graphical representation of the main effects of all factors is shown in Figure 5. A growing direction of lines means that due to the transition from the low level to the high level of given factors, the effect of factors increases.

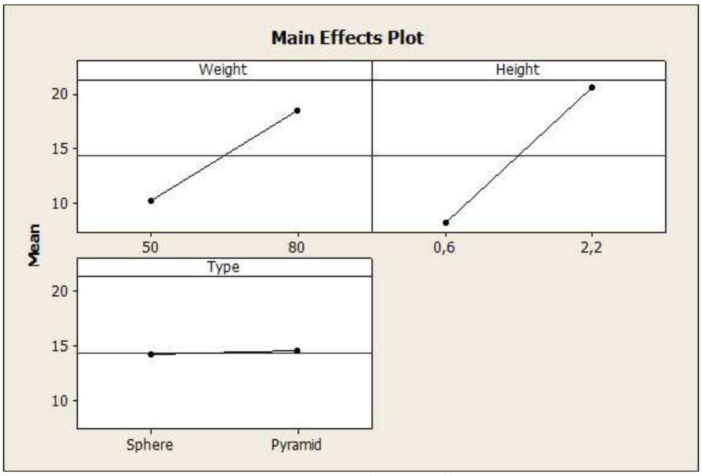

Fig. 5. Graphical Representation of Main Effects (Minitab Output).

The following plots of interactions between individual factors confirmed that while there is a mild interaction between the A and B factors, there is no significant interaction between other pairs AC, BC (Fig. 6).

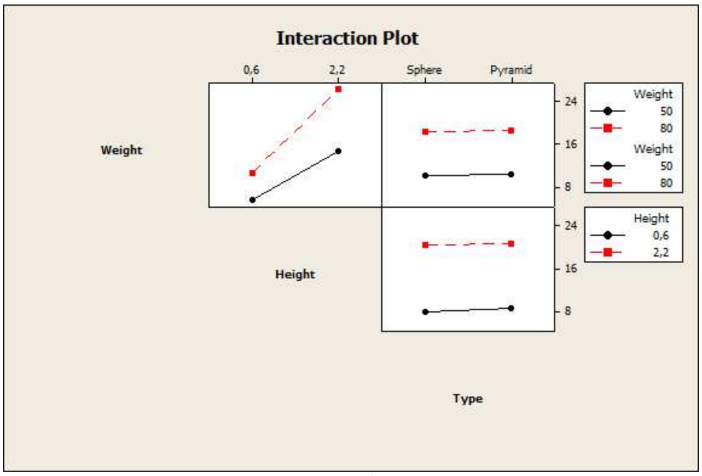

Fig. 6. Graphical Representation of Interactions (Minitab Output).

The evaluation of the planning results indicates that the monitored response is most significantly affected by the drop hammer's drop height (12.455, B factor) and the drop hammer weight (8.325, A factor). The drop hammer head has a negligible effect (0.33, C factor). Impact force curves for "sphere" and "pyramid" drop hammer types for the P 630/3 conveyor belt are shown in Fig. 7. The drop hammer weight is 50 kg and the drop height is 1.6 m. The analysis of the experimental measurement results indicates that the impact force curves are almost identical, with only a negligible time shift of approximately 0.072 seconds. Therefore, we will only execute, and analyse in further measurements, the impact force in case of a sphere-shaped drop hammer end-piece.

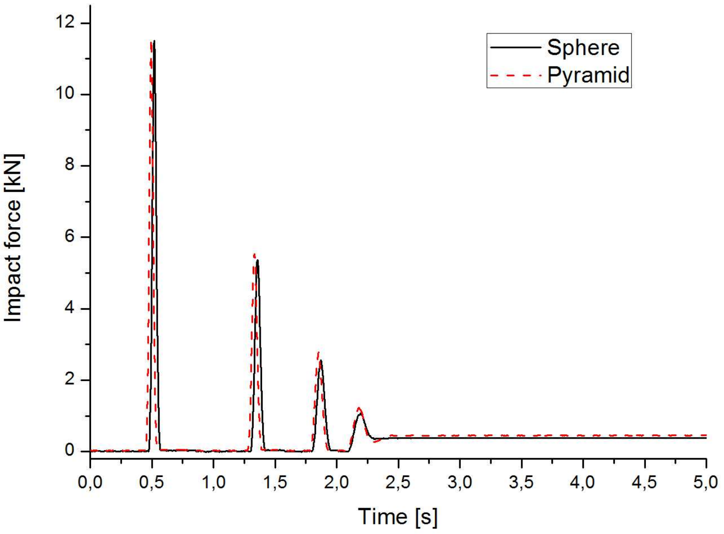

Fig. 7. Impact Force Curve (m=50 kg, h=1.6 m).

Monitoring of the relationship between the impact force local peaks and the time.

On the basis of the obtained results, further experimental measurements were carried out in the second step. The drop height h and the drop hammer weight m were gradually changed within the range determined in the first step of the experiment. The drop height was changed with the 0.2 m difference and the drop hammer weight with the 10 kg difference. The impact force curve in time for the P 630/3 conveyor belt is shown in Figure 8. In all cases, the “sphere-type” drop hammer with the weight of 50 kg falls down from various drop heights. For the purpose of better visualisation, the results shown represent the measurements for the drop height with the 0.6 m difference.

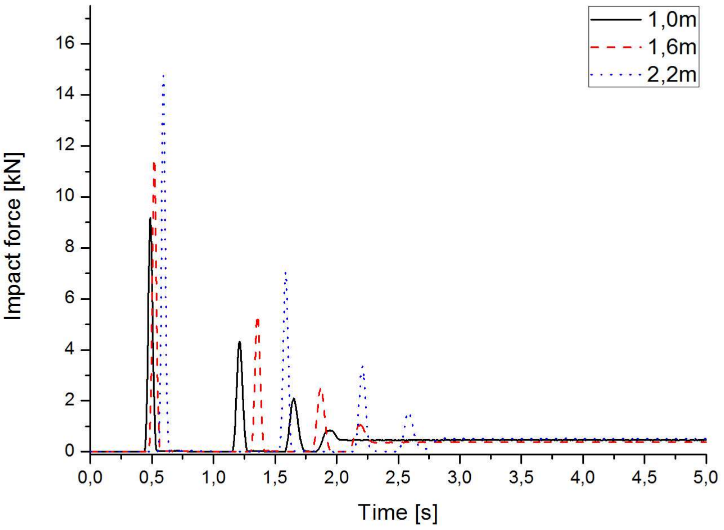

Fig. 8. Comparison of Impact Force in Time for Various Drop Heights (m=60 kg).

The quantity of local peaks within the impact force curve was ranging between 3 and 6, whereas the quantity was slightly growing with the increasing drop height and the increasing weight of the falling drop hammer.

Experimental measurements indicate the decrease in the impact force local peaks in time. We speak about the damping of the impact force evoked by the drop hammer’s impact. The best model for such damping at a respective drop height and drop hammer weight seems to be the following simple linear regression model

$$F_{I,m,h} = \beta_{0,m,h} + \beta_{1,m,h} t + \varepsilon \,, \tag{3}$$

where $F_{I,m,h}$ is the output variable representing the value of the impact force local peaks, t is the time variable (s), $\beta_{0,m,h}$ and $\beta_{1,,m,h}$ are regression model parameters for the drop height h and the drop hammer weight m. The point estimate of the model is

$$F_{I,m,h} = b_{0,m,h} + b_{1,m,h} t \,. \tag{4}$$

As an example, regression models for the case with the 60 kg drop hammer weight are shown at four various drop heights (Fig. 9). Local peaks within individual curves (Fig. 9) represent the impact force local peaks at the respective times for the given weight.

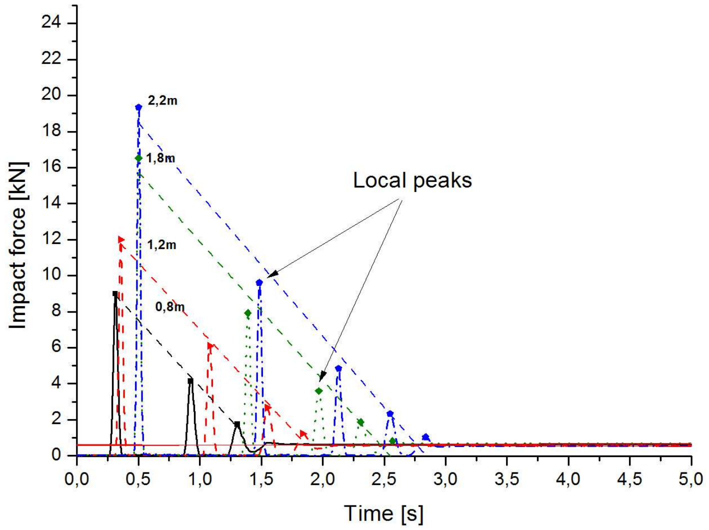

Fig. 9. Impact Force Damping in Time for Various Drop Heights (m=60 kg).

Tab. 3. Resulting Parameters of Regression Models and Correlation Coefficient Values.

Weight	**Model**	**Drop height**								
		0.6 m	0.8 m	1 m	1.2 m	1.4 m	1.6 m	1.8 m	2.0 m	2.2 m
50 kg	b_0	5.85	8.78	11.74	9.53	12.42	14.46	15.44	16.98	18.08
	b_1	-2.81	-5.58	-5.76	-5.84	-6.06	-6.29	-6.43	-6.55	-6.61
	I^2	75.9	99.1	99.1	99.1	99.1	99.1	98.8	99.0	98.2
60 kg	b_0	10.53	11.22	13.21	14.41	17.16	21.95	19.58	21.14	22.41
	b_1	-6.60	-7.38	-7.24	-7.40	-7.57	-7.27	-7.69	-7.98	-7.88
	I^2	99.5	99.4	99.3	99.4	99.1	97.6	98.0	97.7	98.4
70 kg	b_0	15.18	14.87	14.64	16.90	18.63	20.41	22.53	23.38	25.63
	b_1	-6.28	-6.87	-6.50	-6.95	-7.32	-7.71	-8.02	-7.66	-7.98
	I^2	99.3	99.5	98.2	98.6	98.7	98.7	98.8	97.6	97.8
80 kg	b_0	13.19	14.05	16.14	20.23	20.65	22.75	25.18	26.93	28.89
	b_1	-6.20	-6.76	-7.29	-7.56	-8.15	-8.50	-8.26	-8.66	-8.80
	I^2	98.2	98.4	98.5	98.3	98.5	98.5	97.7	97.8	97.9

Regression model parameters, together with the correlation coefficient I^2, for individual drop heights and drop hammer weights are in Table 3. In all cases, regression models and model parameters are statistically significant. The regression and correlation analyses confirmed a very strong linear relationship between the impact force damping-absorption and the time.

Monitoring of the relationship between the impact force local peaks and the drop height.

The following Figures 10 and 11 show the values of impact force peaks (local extremes) for individual drop heights.

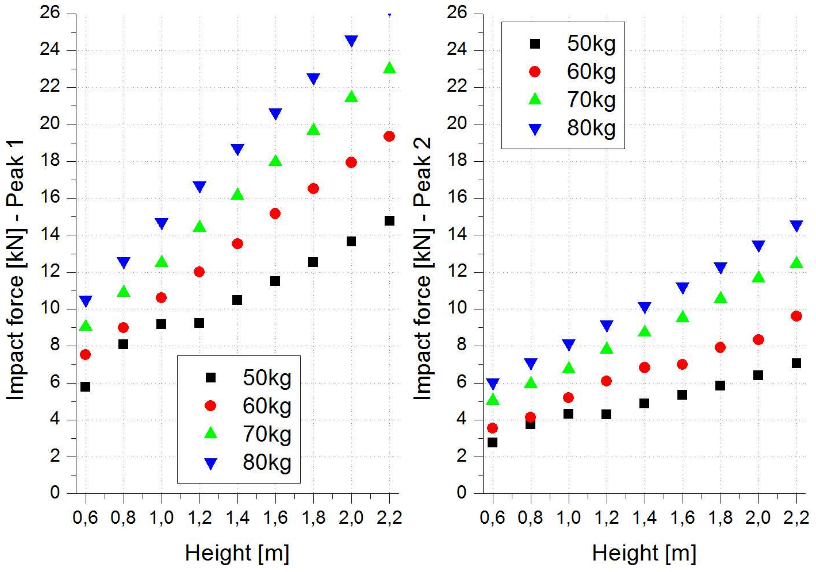

Fig. 10. Impact Force versus the Drop Height (Peaks 1 and 2).

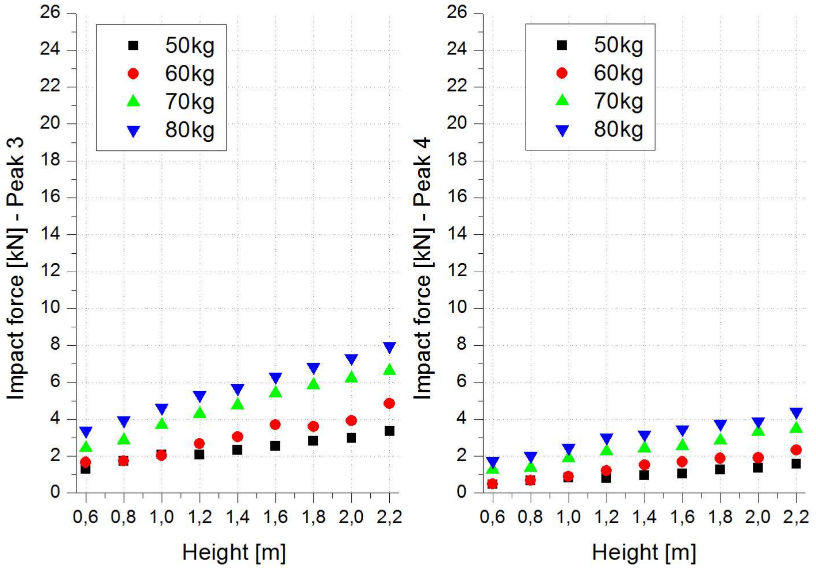

Fig. 11. Impact Force versus the Drop Height (Peaks 3 and 4).

Impact force differences between the values of the local extreme at the highest drop height (2.2 m) and the lowest drop height (0.6 m) are most significant at the first peak (Table 4). This difference gradually decreases.

Tab. 4. Resulting Impact Force Differences between Impact Force Values at the Height of 2.2 m and 0.6 m.

Peak	50 kg	60 kg	70 kg	80 kg
Peak 1	8.97	11.82	13.94	15.78
Peak 2	4.28	6.06	7.40	8.54
Peak 3	2.05	3.18	4.18	4.55
Peak 4	1.10	1.83	2.20	2.67

Local extreme values for a given drop hammer weight are increasing almost linearly with the growing drop height (Fig. 10, 11). By comparing the obtained impact force values and from the plots in Figures 10 and 11 we can see that the decrease in the impact force of individual consecutive peaks (local maximum values) is in the interval of approximately 50-60 %. Therefore, the conveyor belt tested in the experiment is able to absorb, without the support system, approximately 50-60 % of the impact energy.

Monitoring of the relationship between the impact force and the drop hammer weight and the drop height.

Creation of the model for all peaks obtained from the experiment was based on the basic model created for the first impact force local peaks according to (Hardygora, 2002)

$$F_I = b_0 + b_1 \cdot h + b_2 \cdot m + b_3 \cdot h^2 + b_4 \cdot m^2 + b_5 \cdot h \cdot m. \tag{5}$$

The models were determined for the first four impact force local peaks.

For the first impact force local peak, the best regression model is as follows (Eq. 5)

$$F_I = b_0 + b_1 \cdot h + b_2 \cdot m + b_3 \cdot h^2 + b_4 \cdot m^2 + b_5 \cdot h \cdot m.$$
$$F_{I,1} = -4.036 - 2.367 \cdot h + 0.198 \cdot m + 0.156 \cdot h \cdot m - 0.001 \cdot m^2.$$

For the second impact force local peak, the best regression model is as follows (Eq. 6)

$$\begin{aligned} F_I &= b_0 + b_1 \cdot h + b_1 \cdot m + b_2 \cdot h \cdot m. \\ F_{I,2} &= -0.998 - 2.192 \cdot h + 0.046 \cdot m + 0.096 \cdot h \cdot m \,. \end{aligned} \tag{6}$$

For the third and fourth impact force local peaks, the best regression model is as follows (Eq. 7)

$$\begin{aligned} F_I &= b_0 + b_1 \cdot h + b_2 \cdot m. \\ F_{I,3} &= -6{,}669 + 2{,}155 \cdot h + 0{,}117 \cdot m. \\ F_{I,4} &= -4.345 + 1.160 \cdot h + 0.072 \cdot m. \end{aligned} \tag{7}$$

In all cases, the identified regression models are statistically significant. Similarly, the model parameters are statistically significant. Values of multiple regression coefficients are shown in Table 5.

Tab. 5. Resulting Values of Multiple Regression Coefficients.

Peak 1	**Peak 2**	**Peak 3**	**Peak 4**
99.7%	99.4%	94.3%	94.3%

For the first local peaks, model (5) was confirmed. Regression models for other peaks have different forms. This may be caused by the fact that already after the first impact, and also after subsequent impacts of the drop hammer, the conveyor belt absorbed a certain quantity of the drop hammer's kinetic energy. As a result, conveyor belt's internal structure changes and it may affect the height to which the drop hammer is able to bounce after the impact. With a new drop height, the magnitude of the impact force, caused by the subsequent drop hammer's impact, changes as well.

Conclusion

In this article, we have described several mathematic models illustrating the relationship between the impact force induced by the drop hammer's fall onto the conveyor belt in time and carried out the analysis of the effect of the drop height and the drop hammer weight on the impact force magnitude. This analysis represents the basis for further research in this field. Results of mathematic modelling unambiguously indicate that the proposed regression models provide a very good description of the real behaviour of the tested rubber-fabric conveyor belt at the disruption in operations during the dynamic stress caused by the impact force. On the basis of the experience, we may state that the most serious damage to conveyor belts by the falling material is caused particularly by the first falls of the material onto the conveyor belt, where local extremes of the impact force occur. This statement is also confirmed by the obtained regression models for the considered local extremes of the impact force.

A significant effect of the drop height, drop hammer weight, and the interaction between them were also confirmed by the DOE method. Application of this method is appropriate in an experiment with a larger amount of factors, as it identifies the factors significantly affecting the response. The method is very important in the experiment designing and efficient execution, and the process applied within this method leads to the reduction of some required assays; this may bring savings, mainly in terms of time, finances, or materials.

Experiment results may also be used within the examination of how a conveyor belt is able to absorb the energy of the falling material. This knowledge could be used when predicting the service life of conveyor belts, without damaging the conveyor belt used in operation. Such laboratory experiment could be used to estimate the internal damage of conveyor belts which is not detectable by the conventional visual inspection. A multidimensional model facilitates operative setting up of the conveyor belt parameters to maximise the conveyor belt service life. Functional relationships obtained as described above are then used also in optimisation models that minimise the loss during the operation of such technical equipment.

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