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APPLICATION OF DESIGN OF EXPERIMENT METHOD IN THE BELT TRANSPORT

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Abstract: *The method of design experiment is an important powerful tool for the identification of the factors that affect the most important process and its outcomes. The paper deals with the implementation and evaluation of the experiment for monitoring the stress of the conveyor belts in the context with their resistance to breakdown.*

Key words: *Design of experiment, factors, effect of the factors, conveyor belts.*

1 INTRODUCTION

Design of Experiments (DOE) is a method that allows the improvement of knowledge and technology and laboratory processes. The basic concepts are: experiment, factor, output (response), and factor effect. The experiment can be defined as any intervention in the process, in order to observe and measure the effects of this intervention. Variable that represents the output of the experiment is called response variable (output, output variable). Input variables which change in order to assess their impact output called factors. Setting the factors to some value is called factor levels [1, 4, 7]. In planning the experiment, the most commonly used two levels (so-called two-level experiment), usually referred to as the low and high level, which is in short (encoded) form a symbol +1 (resp. "+“), and -1 (or "-").

DOE method is forward planned sequence of experiments in which input factors are changed deliberately, and then identifies the corresponding change response. The main aim of the method is to determine which of the factors entering into the process, resp. their interactions are monitored for output and thus critical to find the optimum setting key input factors.

The planned experiment based upon pre-established plan. This plan sets out the number of performed experiments in which the experiment is made, the conditions under which the various attempts are made, and the order of experiments. The basic process, the planning experiment is divided into several steps [1, 6, 8]

- Determine the object of the experiment.
- Selection of response and definition of factors.
- Design of the experiment.

- Execution of the experiment.
- Evaluation of the experiment.
- Conclusions and recommendations.

Number of observed factors and their level depends on the actual situation of the proposed experiment. When examining the effect of one factor, we are talking about one-factor experiments. If we check the effect *k*-factor to response, we are talking about *k*-factors experiment. In general, factors may have a different number of levels, but most often are designed only two, max. three levels. These proposed experiments will then be referred to 2^k, respectively 3^k, where *k* is the number of factors, a sign corresponding to the number of attempts to be implemented in the proposed experiment.

2 DESIGN AND EVALUATION OF EXPERIMENT

At the beginning of the planning of the experiment object, goal of the experiment, input and output factors are terminated. In the proposed experiment, we monitor the effect of the four factors (Table 1): the weight of ram (factor A), the height of ram falling (factor B), type of conveyor belt (factor C) and type head of ram (factor D). The aim of the design of experiment is to determine which of the factors and their interactions significantly affect the size of the impact force Fr [in kN] acting under the impact load on the conveyor belt (response Y).

Table 1 *Input factors and their levels*

Level	Weight of ram [kg]	Height of ram falling [m]	Type of conveyor belt	Type head of ram
	A	B	C	D
Low (-)	50	0.6	P630/3	Spherical head
High (+)	80	1.6	P2000/4	Pyramid head

There are several ways to prepare a plan under which the experiment will be carried out. The most common plans include a full factorial design. In full factorial experiment with four factors are possible 2^4 = 16 trials which together with the values of individual factors and output variable (response) Y are in Table 2.

Table 2 *Design of experiments with input and output values*

Run		A [kg]	B [m]	C	D	Y [kN]
1	*(1)*	50	0.6	P630/3	Spherical head	5.285
2	*a*	80	0.6	P630/3	Spherical head	10.500
3	*b*	50	1.6	P630/3	Spherical head	11.509
4	*ab*	80	1.6	P630/3	Spherical head	20.635
5	*c*	50	0.6	P2000/4	Spherical head	7.333
6	*ac*	80	0.6	P2000/4	Spherical head	10810
7	*bc*	50	1.6	P2000/4	Spherical head	15.435
8	*abc*	80	1.6	P2000/4	Spherical head	22.176
9	*d*	50	0.6	P630/3	Pyramid head	5.916
10	*ad*	80	0.6	P630/3	Pyramid head	10.872
11	*bd*	50	1.6	P630/3	Pyramid head	11.553
12	*abd*	80	1.6	P630/3	Pyramid head	20.886
13	*cd*	50	0.6	P2000/4	Pyramid head	7.736
14	*acd*	80	0.6	P2000/4	Pyramid head	13.187
15	*bcd*	50	1.6	P2000/4	Pyramid head	15.613
16	*abcd*	80	1.6	P2000/4	Pyramid head	25.286

The general plan of full factorial experiment with two levels without repeating with the coded variables is in Table 3. The low level of the factor is indicated by "-" and the high level of "+". For determining the optimal level of factors is also important to know which the pair (trio, quartet) factors have significant interaction with each other. Sign of the interactions are obtained by multiplying the corresponding marks in columns [6].

Table 3 *The 2^4 design of experiment with factors and their interaction*

Run		A	B	C	D	AB	AC	AD	BC	BD	CD	ABC	ABD	ACD	BCD	ABCD
1	*(1)*	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+
2	*a*	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-
3	*b*	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-
4	*ab*	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+
5	*c*	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-
6	*ac*	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+
7	*bc*	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+
8	*abc*	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-
9	*d*	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-
10	*ad*	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+
11	*bd*	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
12	*abd*	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-
13	*cd*	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+
14	*acd*	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-
15	*bcd*	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-
16	*abcd*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

In the next step we are interested not only in effect of the individual factors, but also in their interaction. The effect factor is defined as the change of response caused by changing levels of the factor. If these are some of the main factors, we are talking about the main effect factor.

Calculation of the main effect factors can be done in several ways. In 2^k experiments, the effect of the factors A, B, C and D can be calculated as the difference between the effect on the "+" and "-", in other words the difference in the average responses of the high and low levels factor. Applicable

$$effect\,(A) = \bar{y}_{A+} - \bar{y}_{A-}\,, \tag{1}$$

$$effect\,(B) = \bar{y}_{B+} - \bar{y}_{B-}\,, \tag{2}$$

$$effect\,(C) = \bar{y}_{C+} - \bar{y}_{C-}\,, \tag{3}$$

$$effect\,(D) = \bar{y}_{D+} - \bar{y}_{D-}\,, \tag{4}$$

where $\bar{y}_{A+}$, $\bar{y}_{A-}$, $\bar{y}_{B+}$, $\bar{y}_{B-}$, $\bar{y}_{C+}$, $\bar{y}_{C-}$, $\bar{y}_{D+}$ and $\bar{y}_{D-}$ indicate averages of the results for a given level factor [4].

In four-full factorial experiment can be a main effect factor A calculated according to the equation:

$$effect(A) = \bar{y}_{A+} - \bar{y}_{A-} = \frac{1}{8}\left[\sum y_{A+} - \sum y_{A-}\right] = \tag{5}$$

$$= \frac{1}{8}\left[a + ab + ac + abc + ad + abd + acd + abcd - (1) - b - c - bc - bd - cd - bcd\right].$$

Positive result of effect indicates that by increasing factor A, tracked response Y increases as well; also determines a main effect of other factors B, C and D (Table 4).

Estimated effect of interactions between factors can be determined by the relationship

$$effect(AB) = \frac{1}{2}\left[\left(\bar{y}_{A+B+} - \bar{y}_{A-B+}\right) - \left(\bar{y}_{A+B-} - \bar{y}_{A-B-}\right)\right], \quad (6)$$

where for example $\bar{y}_{A+B+}$ means the average of results for combinations of the levels A+B+.

Table 4 *Main effects*

	A	B	C	D
$\bar{y}_{\bullet-}$	10.0475	9.0799	12.1445	13.0853
$\bar{y}_{\bullet+}$	16.9190	17.8866	14.8220	13.8811
Effect	6.8715	8.8067	2.6775	0.7958

Graphical representation of the main effects of all the factors shown in Figure 1. Increasing straight line means that the transition from the low to the high level of the factors increasing effect factors. The analysis shows that the largest observation impact force acting on impact load on the conveyor belt is achieved when all four factors set the high level.

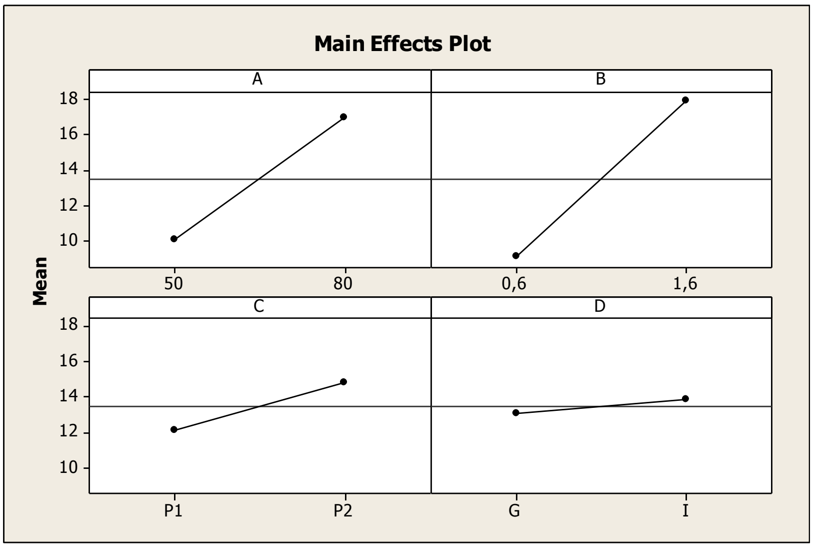

Figure 1 *Main effects plot*

Effects of all the main factors (A, B, C, D) and interactions (AB, AC, AD, BC, BD, CD) are presented in the output from the Minitab [5]:

```
Term        Effect    Coef      SE Coef     T       P
Constant             13.4833    0.1579  85.38   0.000
A           6.8715    3.4358    0.1579  21.75   0.000
B           8.8067    4.4034    0.1579  27.88   0.000
C           2.6775    1.3388    0.1579   8.48   0.000
D           0.7958    0.3979    0.1579   2.52   0.053
A*B         1.8468    0.9234    0.1579   5.85   0.002
A*C        -0.2860   -0.1430    0.1579  -0.91   0.407
A*D         0.4818    0.2409    0.1579   1.53   0.188
B*C         0.8043    0.4021    0.1579   2.55   0.052
B*D         0.1000    0.0500    0.1579   0.32   0.764
C*D         0.4713    0.2356    0.1579   1.49   0.196
```

The results show that the greatest effect on observed response has the factor A (weight of ram) and factor B (height of ram falling). Factor D (type head of ram) has a very minor impact. The significance of individual factors' influences resp. interactions is tested using the t-test, and in the output of the program is reflected by the p-value. It is true that the effect of factors, respectively interaction is not statistically significant, if the p-value is greater than 0.05. The analysis shows that the three main factors A, B, C and interaction AB have statistically significant effect on response, i.e. the output value of the impact force Fr.

For evaluating the effect of individual factors and their interactions is preferred to use two charts: Pareto chart (Fig. 2) and normal probability plots (Fig. 3). In the case of normal probability plots, all the factors and interactions that are outside the plotting lines are considered to be significant. From the two charts is already known that a considerable effect on the response has weight of the ram (factor A), the height of ram falling (factor B), type of conveyor belt (factor C) and the interaction of the first two factors AB [5, 6].

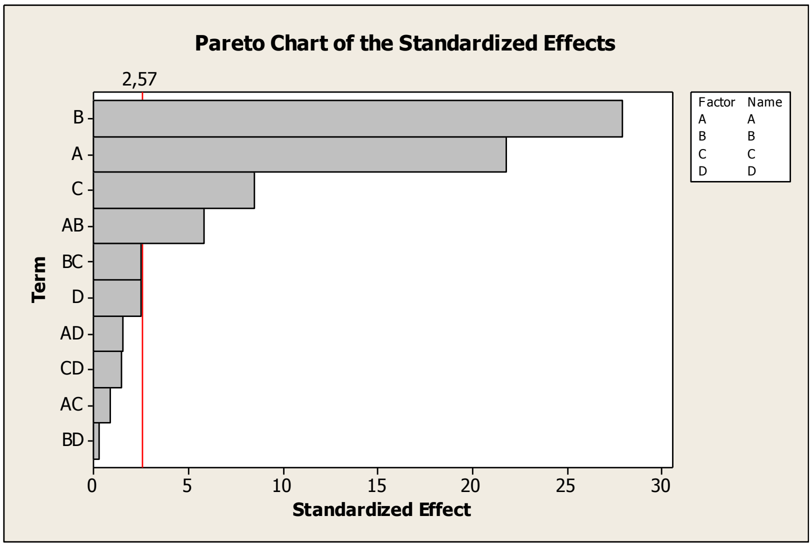

Figure 2 *Pareto chart*

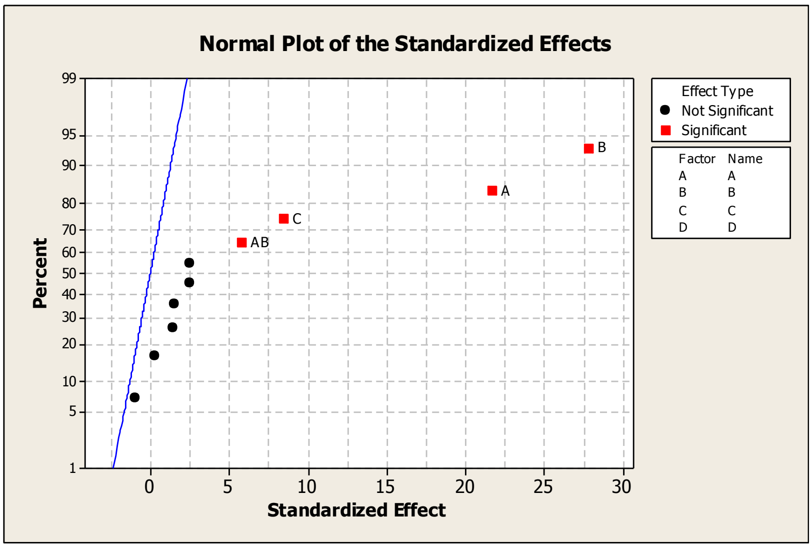

Figure 3 *Normal probability plot*

The following graphs of interactions between factors confirmed that while between factors A and B is a mild interaction, then the others two-factor interactions AC, AD, BC, BD and CD are no significant (Fig. 4).

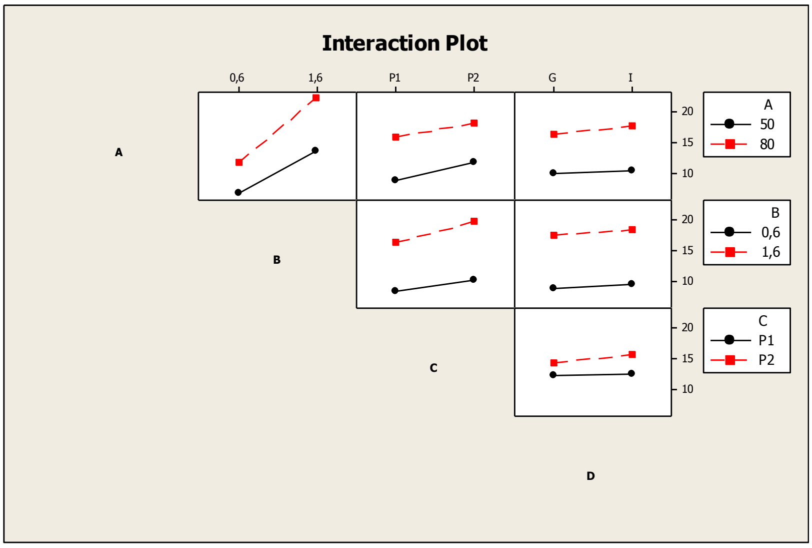

Figure 4 *Interaction plot*

3 CONCLUSION

Experiment of the monitoring stress of the conveyor belts was carried out at a test facility which is located at the Logistics Institute of Industry and Transport, Faculty of Mining, Technology, Process control and Geotechnologies in Košice [2]. Testing methodology was taken from authors Grinčová, Hlúbiková, Kresak [3], the method was developed based on a review of all appropriate methods designed specifically for testing conveyor belts as described in [9]. The aim of the experiment was to evaluate the effect of input factors on the impact force. The results show that the size of the impact force expected to be the largest effect weight of ram, height of ram falling, type of conveyor belt and the interaction of the first two major factors. In examining the height of ram falling (from 0.6 m to 1.6 m) as an insignificant factor seems to be the last major factor: the type of ram. They are also other interactions between factors, which are considered to be insignificant (in addition to the interaction between the weight and height of impact ram). The next step would be to evaluate the results of the experiment and analysis using a regression model, which puts into relation input and output variables.

Design of the experiments is a powerful and important tool, which makes possible to find the factors that significantly affect the process. It is based on the fact that by various input variables and observing the responses of output, is possible to get to know the process better and then improve it. Using this method is advantageous in an experiment with a large number of factors; as it reveals the factors that significantly affect the touch. The DOE method is very important in planning and implementing effective experimental procedure and its results lead into reducing the number of necessary tests, which may result in mainly time, financial and material savings.

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