Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 87, 2014: 84-89
(Ann. WULS - SGGW, For. and Wood Technol. 87, 2014)

Experiment planning and evaluation of the outcomes

ĽUBOMÍR JAVOREK – MARTA KUČEROVÁ

Abstract: The paper discusses the process of experiment planning as well as the usage of the method known as *design of experiments*. The principles of experiment planning were applied by the authors when machining for two-factors and two-lewels experiment. Variables were depth of cut, cutting speed, constants were sample of wood and feedspeed.

Keywords: experiment, planning, evaluation of effects, exponential equation

INTRODUCTION

Every research consists of a theoretical and an expertimental part, the latter verifying the data set by the former. However, it often is the other way round, too – when theory searches for such a mathematical processing of measured data that would bring as congruent result as possible. The calculations should be as simple as possible and make use of symbols which are familiar for the reader. Experiments represent a fundament for modelling theoretical speculations or they verify theses speculations. To sum it up, they are used for setting or verifying mathematical calculations.

Experiments can be carried out on model machines or in real situations. Nevertheless, if we want to get an applicable result, the conditions of the experiment need to include all the significant factors of the real situation.

The goals of an experiment are:

- to set the values of a given parameter for all other constant parameters
- to set the values of a given parameter for different values of other parameters (independent variables) and identify their mathematical dependence

The crucial part of an experiment is the procession and evaluation of measured data, as well as the decision whether the examined parameters (factors) do have an influence on the observed parameter or not.

Standard phases of an experiment are:

1. Analysing the process
2. Designing the experiment
3. Conducting the experiment
4. Analysing the outcomes
5. Conclusions and recommendations

For result analysis, methods for hypotheses testing are used: t-test, F-test, scattering or covariation analysis, regression analysis, optimization methods, etc.

Processing the result by various mathematical methods can be an "appropriate way of directing" the reader in the decision-making process.

The production of every part is aimed at achieving maximal congruence with designed parameters and prescribed surface quality (within the limits of allowed parameter and form tolerance).

The SNOP-system (machine-tool-fixture-piece; (in Slovak: Stroj– Nástroj – Obrobok –Prípravok) is entered by individual elements as well as a number of factors (qualities, independent variables), which might influence the parameters of the outcomes in many ways.

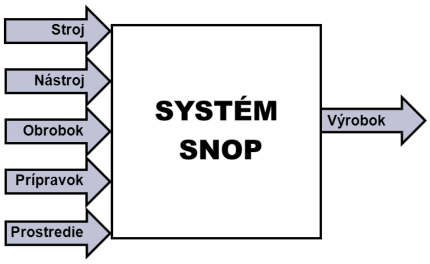

Fig. 1 Parts of working system

Each of these elements has certain qualities, which influence both its own quality parameters and the general response of the system. Principally, the elements can be divided into these groups:

- factor elements: used to identify important factors in an experiment
- experiments aimed at searching for optimal response = solutions: used to search for optimal combination of factor values that would make the optimal value of the response
- mixture designs = experimens
- optimal designs.

The group of factor experiments also includes: one-factor experiments; complete accidental blocks; Latin squares; incomplete accidental blocks; more-factor dox-Hunter's experiments are derived from factor experiments; Taguchi's experiments, Plachett-Burman's experiments.

GOAL AND METHODOLOGY

In the next part, the outcomes of the experiment with machining with router are processed.
The independents variables were: depth of the cut and cutting speed. The dependent variable was force in the direction of the movement. The aim of data processing was received formula, that will reflect, directly, parameter, that can be changed.

Design of total more factorial experiment contends all combination of N-factors on all levels of their variations. For evaluation of measured values was used factorial experiment of type p; k, where k is number of factors and p is number of factor levels, i.e. total number of all experiment is p^k. The most frequent number of levels is p = 2, interior and superior. So that number of our experiments will be $N = 2^2 = 4$
The graphic illustration of two factorial experiment is in Fig. 1, where x1 and x2 are factors individual test are marked by figures (k = 2).

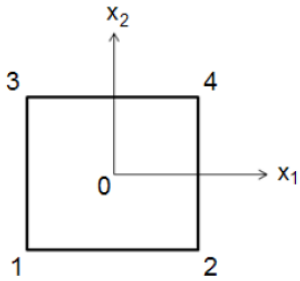

Fig.1 The graphic illustration of two factorial experiment (1 - 4 are individual test, x1 and x2 are factors of experiment, k is number of factors)

For natural values of factor at inferior and superior level are allocated coded value +1, -1, 0. The aim of this coding is simplification of mathematic operation for calculating of results. Coded values of all factors for particular test are consolidated in table named matrix of experiment. One column is associated for every factor; one line is associated for every test. One column with imaginary factor x_0 is added for more simple calculation and witch has weight +1 in all tests. [4].

Evaluation of factors level

Inferior (low) level of factor depth of cut $a_{p,min}$ = 1 mm, superior (high) level of factor depth of cut $a_{p,max}$ = 3 mm, inferior (low) level of factor cutting speed $v_{c,min}$ = 14,6 $m \cdot s^{-1}$ and superior (high) level of factor $v_{c,max}$ = 20,9 $m \cdot s^{-1}$. Feed speed is constant ant its value is v_f = 1400 $mm \cdot min^{-1}$[1, 5].

The standards values for both factors (depth of cut $a_{p,0}$ and cutting speed $v_{c,0}$ can be specify by formula (1) [4]:

$$a_{p,0} = antilog\frac{loga_{p,max}+loga_{p,min}}{2}; \text{ [mm; mm, mm]} \quad (1)$$

where: $a_{p,0}$ ... standard value for factor depth of cut [mm],
$a_{p,max}$ ... superior level for factor depth of cut [mm],
$a_{p,min}$ ... inferior level for factor depth of cut [mm].

$$v_{c,0} = antilog\frac{log\ v_{c,max}+log\ v_{c,min}}{2}; \text{ [m.s}^{-1}\text{; m.s}^{-1}\text{, m.s}^{-1}\text{]} \quad (2)$$

where: $v_{c,0}$ ... standard value for factor cutting speed [$m \cdot s^{-1}$],
$v_{c,max}$ ... superior level for factor cutting speed [$m \cdot s^{-1}$],
$v_{c,min}$ ... inferior level for factor cutting speed [$m \cdot s^{-1}$].

After substitution in an equation:

$$a_{p,0} = antilog\frac{loga_{p,max}+loga_{p,min}}{2} = antilog\frac{log3+\log 1}{2} = 1{,}73\ mm \quad (3)$$

$$v_{c,0} = antilog\frac{logv_{c,max}+logv_{c,min}}{2} = antilog\frac{log20{,}9+\log 14{,}6}{2} = 17{,}4683\ m \cdot s^{-1} \quad (4)$$

Determination of the basically identities z_1 a z_2 from formulas (3,4), are for evaluation of standard value and than for determination of coded factors x_1 a x_2 [2,3]:

$$z_{1,\min(ap)} = \frac{a_{p,min}}{a_{p,0}} \quad (5)$$

$$z_{1,\max(ap)} = \frac{a_{p,max}}{a_{p,0}} \quad (6)$$

respectively:

$$z_{2,\min(vc)} = \frac{v_{c,min}}{v_{c,0}} \quad (7)$$

$$z_{2,\max(vc)} = \frac{v_{c,max}}{v_{c,0}} \quad (8)$$

where: z_1, a z_2 are the basically identities of depth of cut and cutting speed ,
and: $a_{p,min,\ max}$ ... inferior and superior level for factor depth of cut [mm],
$v_{c,min,\ max}$ ... inferior and superior level for factor cutting speed [$m \cdot s^{-1}$],
$a_{p,0}$ ... standard value for factor depth of cut [mm],
$v_{c,0}$ ... standard value for factor cutting speed [$m \cdot s^{-1}$].

After substitution in an equation (5), (6), (7), (8):

$$z_{1,\min(ap)} = \frac{a_{p,min}}{a_{p,0}} = \frac{1}{1,73} = 0,578 \quad (9)$$

$$z_{1,\max(ap)} = \frac{a_{p,max}}{a_{p,0}} = \frac{3}{1,73} = 1,734 \quad (10)$$

resp.

$$z_{2,\min(vc)} = \frac{v_{c,min}}{v_{c,0}} = \frac{14,6}{17,483} = 0,835 \quad (11)$$

$$z_{2,\max(vc)} = \frac{v_{c,max}}{v_{c,0}} = \frac{20,9}{17,483} = 1,195 \quad (12)$$

Coded factors we can determined by formula:

$$x_{i,min/max} = \frac{2\,(log z_{i,min/max} - log z_{i,max})}{log z_{i,max} - log z_{i,min}} + 1 \quad (13)$$

where: $x_{i,min/max}$ ... inferior/ superior coded factor [-],
$z_{i,\ min\ /max}$ ... standard value for inferior/superior level (in our case depth of cut and cutting speed),

After input of value's to formula (13) we received values of coded factors that are in Table 1, in columns 7 and 8.

Tab. 1 Metric's of experiment design and data evaluation (Fa .. average value of 8 repetition)

1	2	3	4	**5**	6	7	8	9	10	11	12	13	14
Test num-ber	x_1 Depth of cut (mm)	x_2 Cutting speed ($m \cdot s^{-1}$)	F_a (b_D=1cm) (N)	y_i=log F_a (N)	x_0	x_1	x_2	$x_{1i} \cdot y_i$	$x_{2i} \cdot y_i$	F_a (b_D=1cm) (N) (manually)	ŷ	F_a (b_D=1cm) (N) (by soft-ware)	ŷ
1	1	14,6	2,55	0,4065	1	-1	-1	-0,4065	-0,4065	1,968	0,294	2,48	0,394
2	1	20,9	1,87	0,2718	1	1	-1	-0,2718	0,2718	1,44	0,158	2,05	0,311
3	3	14,6	4,77	0,6785	1	-1	1	0,6785	-0,6785	3,57	0,552	4,82	0,683
4	3	20,9	4,04	0,6064	1	1	1	0,6064	0,6064	2,89	0,460	3,94	0,595
				1,9632	4			0,6066	-0,2068		1,464		**1,983**

In next step is necessary to evaluate computing of regression coalition's, which express modification of variable's depend (its average value) if in depend variables is change.

Regression coefficients for Fa are computed by formula 14 [4]:

$$b_j = \frac{1}{N} \cdot \sum_{i=1}^{N} x_j \cdot y_i \quad (18)$$

where: bj ... regretion coefficients for calculation of F_a,
N ... number of test,
x_j ... coded factor,
y_i ... logarithm of depend parameter.

After input to formula (14) we receive value regression coefficients that are in Tab. 2:

Tab. 2 Regression coefficients

b_0	b_1	b_2
0,4908	0,1515	-0,0517

Regression coefficients are needed for build-up of regression line for F_a [1]:

$$\hat{y} = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 \qquad (15)$$

where: b_0; b_1; b_2 ... regression coefficients

$$\hat{y} = \log F = b_0 + b_1 \cdot \frac{2\cdot(\log z_1 - \log z_{1max})}{\log z_{1max} - \log z_{1min}} + b_2 \cdot \frac{2\cdot(\log z_2 - \log z_{2max})}{\log z_{2max} - \log z_{2min}} \qquad (16)$$

From this formula, by mathematical operation we receive next formula:

$$F_a = C_F \cdot \left(\frac{a_p}{1{,}73}\right)^{0{,}635} \cdot \left(\frac{v_c}{17{,}468}\right)^{-0{,}664} \qquad [\text{N; - , mm, m}\cdot\text{s}^{-1}] \qquad (17)$$

Or next form:

$$F_a = C_{Fa} \cdot a_p^{0{,}635} \cdot v_c^{-0{,}664} \qquad [\text{N; - , mm, m}\cdot\text{s}^{-1}] \qquad (18)$$

where: C_{Fa}... constant [= 10,849] (it is not the same as C_F)

Some from modern statistical software offer possibility for data processing; after using of softwer Statistica we receive follows formula:

$$F_a = 10{,}47 \cdot a_p^{0{,}629} \cdot v_c^{-0{,}544} \qquad [\text{N; - , mm, m}\cdot\text{s}^{-1}] \qquad (19)$$

Compare both we see, that similarity is quite good and for practical calculation in practice is possible to use conventional, traditional system of calculation.
From this formula is evident, that exponent of depth of cut is much more like exponent of feed speed, it means that depth of cut has greater influence to value of force Fa during this interval of both independent parameters.

This fact is illustrated in Fig. 2 (Paret diagram).

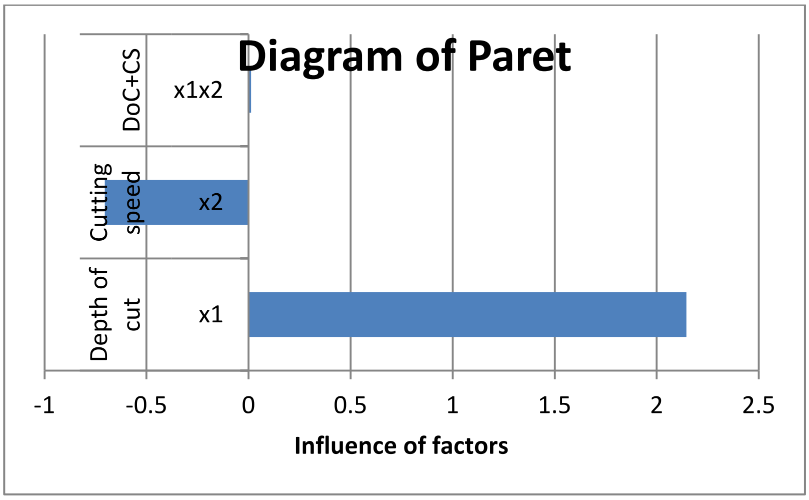

Fig.2 The Paret diagram of factors influence

CONCLUSION

This contribution shows way how to receive exponential formula(s) together with very simply methods for design of experiments. The Paret diagram and ways of design of experiments (Tagutchi metod) afford opportunity for reduction very extensive experiment with observance of high vital statistic plausibility of results.

REFERENCES
1. JAVOREK, Ľ. ; OSWALD, J., 2001: Silové charakteristiky pri obrábaní dreva I – Frézovanie. VŠ 4/2001/B, ES TU Zvolen, s.59. ISBN 80-228-1082-7
2. KUČEROVÁ, M., 2010: Uplatnenie metódy plánovania experimentov v manažérstve kvality (using methods of design of experiments in quality management), Trnava, AlumniPress, s. 92. ISBN 978-80-8096-112-1 EAN 9788080961121
3. KUČEROVÁ, M., 2012: Stanovenie úrovní vstupných faktorov pri procese popúšťania drôtu metódou DOE. In. Transfer inovácií 23/2012, s.159-163
4. LIPA, Z., 2001: Vzájomné vzťahy teoretickej a praktickej drsnosti sústruženého povrchu. In Zborník medzinár. konf. TECHNOLÓGIA 2001. Bratislava, SjF, 2001.
5. OČKAJOVÁ, A.; SVOREŇ, J.; JAVOREK, Ľ.; OSWALD J. (1995): Energetický význam hrúbky úberu pri cylindrickom frézovaní. In.: Acta Facultatis Xylologiae XXXVII. Zborník vedeckých prác Drevárskej fakulty Technickej univerzity vo Zvolene 1995/I. s. 279÷284. ISBN 80 - 228 - 0438 - X

Streszczenie: *Planowanie eksperymentu i ocena wyników.* Praca opisuje proces planowania eksperymentu oraz utylizację metod jego planowania. Zasady planowania eksperymentu zostały zastosowane do dwuczynnikowego i dwupoziomowego procesu obróbki mechanicznej. Zmiennymi były głębokość cięcia, prędkość skrawania zaś stałymi gatunek drewna oraz prędkość posuwu.

Corresponding authors:

Ľubomír Javorek
Faculty of Environmental and Manufacturing Technology
Technical university in Zvolen
T. G. Masaryka 24
SK - 960 53 Zvolen
e-mail: lubomir.javorek@tuzvo.sk

Marta Kučerová
Institute of Industrial Engineering and Management
Faculty of Material Science and Technology in Trnava
Slovak University of Technology in Bratislava
Paulínska 16
SK - 917 24 Trnava
e-mail: marta.kucerova@stuba.sk